U.S. NAVAL AIR MATERIAL CENTER

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AIR CREW EQUIPMENT LABORATORY

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PROBLEM ASSIGNMENT NO. 005-AE13-14
SPACE SUIT: DETERMINATION OF THE GEOMETRY AND MINIMUM VOLUME OF THE ENVELOPE REQUIRED FOR DONNING AND DOFFING OF

Geometric and Volumetric Determinations of the Minimal Envelope for Donning the Full Pressure Suit

NAEC-ACEL-503 1 JULY 1963

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ADMINISTRATIVE INFORMATION

Defense Purchase Request T-7716G of 15 May 1962 was assigned to the Air Crew Equipment Laboratory by the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston 1, Texas. This study was conducted to determine the minimum volume and internal geometry of an envelope which will permit the donning and doffing of the full pressure or space suit. An extension of 100 days was requested by NAVAIRENGCEN letter XG-436:BHL:alc T-7716G/005-AE13-14 (4080) of 30 October 1962 and was granted by NASA on 12 February 1963. This report is in fulfillment of the subject NASA Purchase Request.

This study was conducted in collaboration with Mr. Paul F. Kuehl, Technical Monitor, Life Systems Division, NASA (MSC).

ABSTRACT

Upon the request of the National Aeronautics and Space Administration (Manned Spacecraft Center), an investigation was conducted to determine the geometry and internal volume of the minimal envelope for donning the full pressure suit. Specialized techniques were evolved to achieve a systematically variable, transparent, rigid encapsulation of the subject, as well as a parallax-free method for determining the gross three-dimensional excursions of the suit/body silhouette from the nominal configuration. The precise limits of the donning geometry were determined using photoanalysis techniques. Subsequent to the determination of donning geometry, the internal volume was systematically reduced in step-wise decrements along the spherical diameters from the seat reference point, and at each decrement, time to don was recorded. Volumetric and geometric determinations were made on 5th and 95th percentile subjects.

INTRODUCTION

Considerations for crew comfort in space flights of increasing duration turn quite naturally to the full pressure suit and present requirements for continuous wear of that garment. It is by no means certain what the cumulative stress effects of long term wear of this garment are, nor at what point it becomes crucial to shift from a continuous wear garment to a partial or intermittent wear suit. Contemplated for the GEMINI mission is a constant wear suit having access provisions for performance of excretory functions. Since the projected mission time for GEMINI may be as long as fourteen days, the GEMINI program appears to be approaching the limiting conditions of habitibility for constant wear suits. At any rate, the cabin volume of the GEMINI vehicle will not permit the removal of the entire suit in flight, in which case no further concessions to crew comfort may be made, desirable though they may be.

With respect to the APOLLO and subsequent vehicles, a modicum of space will likely be available for donning and doffing the suit in flight, assuming the volumetric requirements for this purpose are not too great. In addition to the volumetric limitations, presumption of a "shirt-sleeve" working regime implies an overall pressure protective capability in the primary vessel to provide the astronauts with adequate time—regardless of the severity of the pressure vessel casualty—to don their suits methodically.

Toward these objectives, it becomes pertinent to establish the limiting conditions of volume, geometry, and time for donning the full pressure suit. These data become crucial to the determination of workplace layout, evaluation of developmental suits, and bioengineering of the life support systems.

PRESENT STUDY

This report presents the results of an investigation performed at the request of the National Aeronautics and Space Administration to determine the geometric configuration and associated minimal volume of an envelope which will permit the donning of a given pressure suit garment. In effect, this means establishing the trade-off paradigm between degree of dimensional constriction and suit donning time, allowing operational considerations to be the final arbiter of what constitutes minimal.

In pursuit of the study objectives, there were many considerations which bore directly or indirectly on this problem and which could have enormous influence on the results. Questions concerning the configuration of the pressure suit which would be worn, how much donning effort is permissible to be exacted from the astronaut, whether the man will have any assistance in the donning task, where the suit is located in the undonned configuration, what positional orientation the crewman will be in when donning, what body size has the crewman, what, if any, concurrent tasks the crewman will be responsible for while donning—these and many others have considerable bearing on the resulting configuration of the donning envelope. To many of these questions, answers were not available and, consequently, certain "educated guesses" were made. These assumptions will be discussed in the body of this report. Needless to say, many of them may eventually prove to be in error and will necessitate reappraisal of these results for design purposes.

PART I - GEOMETRIC DETERMINATIONS

Part I of this investigation involved the reasonably precise determination of the geometry described by the subject as he donned the suit under no constraints.* It was felt that once volumetric restrictions were imposed on the subject, he would change his donning pattern in order to utilize the available space more efficiently, in which case it would be impossible to designate a nominal donning geometry. Once the geometry is determined, it is possible to determine the effects of systematic volume reductions independent of changes in the donning geometry.

Apparatus

Figures 1 and 2 are photographs showing a subject in stages of the donning process in the apparatus which has been dubbed the "Variform Capsule" or "V.C." for short. As can be seen, the apparatus consists of a series of transparent acrylic plastic panels mounted on crossbars in such fashion as to render a volume having a reasonably continuous surface. The mounting attachments of these panels incorporate four degrees of freedom—lateral, rotational, vertical, and radial—resulting in a capsule having considerable variability in terms of geometry and volume. Once the capsule is adjusted to the desired configuration, the boundary surface remains fixed and rigid. Inside the capsule is a simple, straight-backed chair fixed to the floor. No attempt was made to simulate any type of acceleration couch or other operational seat. The seat was intended only to provide a modicum of support with a minimum of restriction.

To provide a relatively parallax-free observing and measuring technique, three closed-circuit television cameras were mounted outside of the V.C. and oriented in the three principal viewing axes—front, top, and side. The background for each of these views consisted of nine-foot square opalescent "Plexiglas" panels backlighted with three slimline flourescent lights resulting in a silhouetted image on each television monitor. In setting up and calibrating the television cameras, companion grids having a scale factor of 8:1 were used. The large grid of the pair was placed in either the median sagittal, frontal, or transverse plane of the body position within the capsule. The respective camera was then focused and aligned to permit congruence between the small grid of the pair, located over the monitor face, and the image of the large grid which appeared on the CRT. Once this process had been accomplished for each camera, the large grid was removed from inside the capsule. When the subject entered the capsule, the effect was a scaled-down picture of the subject's silhouette superimposed on a rectangular grid appearing at the subject's true median body planes.

Fitted to the television monitors were Auricon cameras with T.V. synchronous shutters which provided a permanent motion picture record of the donning sequence for later analysis. Figure 3 shows a printed excerpt from the motion picture record. An attempt was made to include simultaneous views of each monitor

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*Note - No literature references are cited in this report because none were found which had any bearing on the three-dimensional description of cumulative, whole-body motion while donning a garment within a systematically confined space.

on a single filmstrip. This, however, introduced a subsequent parallax error due to the location of the camera with respect to extreme portions of one or more of the monitors. The best rendition that could be achieved was a composite two-view filmstrip of either top/front or side/front views. This proved to be no problem in later analysis.

Standard Navy MK IV full pressure suits were utilized in the study because of their ready availability in sufficient quantity at the ACEL. While it may be argued that the investigations would have been more valid had more advanced type garments been employed, the MK IV suit is at least sufficiently akin to the MERCURY suit to permit a reasonable generalization of results to that garment. Essentially, any pressure suit which conforms to the configuration of the human body will, of necessity, correspond in large measure to the MK IV suit.

Subjects

Two groups of two subjects were utilized in this study—a 95th percentile group and a 5th percentile group—composed of officer and enlisted personnel at the Air Crew Equipment Laboratory. Table I shows the actual magnitudes of five critical morphological dimensions of the four subjects. The percentile figures are based on an anthropometric survey of U.S. Navy pilots.* In addition to the body size criterion, subjects were chosen on the basis of prior experience in the wear of the full pressure suit as well as the availability of a suit in the laboratory's inventory which would fit them. Most of the subjects used, even though they had worn the suit many times, had had little or no occasion to don the suit unassisted. All subjects were, therefore, given several practice sessions prior to the recorded trials for the purpose of training them to a nominal plateau of donning proficiency.

Procedure

Subjects were first fitted to suits, adjusted in the same fashion as would be done were the subjects to be actually pressurized. These suits were then reserved for the duration of the study to prevent any changes being made in the fit. Prior to each session, the suit closures were lubricated for ease of operation, all zippers were fully opened and all tiedowns (with the exception of the helmet and cross chest tiedowns) were placed loosely in their respective adjustment slides. The suit and associated gear were placed in the V.C. in the following pre-don configuration: basic suit folded compactly forward of the seat in such fashion as to expose the open entranceway; left boot and glove and right boot and glove placed together on respective sides of the seat on the deck; and helmet placed in the recess underneath the seat. Prior to donning, the subjects were attired in standard cotton two-piece long underwear with athletic socks.

The configuration of the V.C. apparatus for the geometric determinations was an arbitrary one based on informal observations of practice donning sessions.

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*Note - As can be seen, designation of subjects as aggregate 5th or 95th percentile is purely arbitrary. A true 5th or 95th percentile subject is a theoretical fiction not found in the flesh. Our subjects could, in fact, more accurately be described as "small" or "large."

The objective was to constrain the subjects to a fixed location relative to the T.V. cameras without imposing any restrictions to the free manipulation of the body or the suit. Subjects were subsequently questioned as to the adequacy of the volume and their comments indicated no interference.

The subject was placed in the V.C. and given instructions to begin donning on signal and proceed as rapidly as possible short of making errors of haste. Each subject was also instructed that donning would be complete only when he felt that the integrity of the suit was adequate to the point where he would be willing to undergo immediate decompression. He was told to give a "thumbs up" signal at that point and the sequence would be at an end. Timing was accomplished by means of a standard stop-watch.

While there were some variations between subjects and between sessions, the typical donning sequence was as follows:

1. Left leg placed in suit up to knee, leg zipper closed and left boot donned and zippered;

2. Right leg et. seqq.

3. Subject stands and works suit up torso, left arm placed in sleeve, right arm placed in sleeve;

4. Surplus bladder gathered in gusset and neck ring pulled up and over the head;

5. Gusset zipper closed, entrance zipper closed, neck zippers and snaps secured;

6. Subject sits and cinches all tiedowns;

7. Helmet donned and neck ring engaged;

8. Left glove donned and zippered (Ss learned a helpful technique of starting the zipper before engaging the wrist cuffs, thus making the one-handed manipulation of the glove easier), restraining straps adjusted;

9. Right glove et. seqq.

The precedence of left over right in this sequence is no mere artifact of subjective preference; due to the peculiar construction of the suit, left over right was often the more efficient procedure.

Donning time and movements for each subject were recorded either two or three times in the unrestricted condition (sufficient to get a base time and motion pictures for analysis). The results reflect a composite base time score and donning profile for each subject for all runs.

RESULTS AND DISCUSSION

Table II is a summary of time scores for each subject for each donning session in the unrestricted configuration. The mean scores, which reflect

considerable differences among subjects with respect to donning proficiency, were later used as baselines to determine the penalty exacted by a reduction in donning volume.

Figures 4a through 7f are the resultant donning profiles. Each number represents a particular subject and each letter subscript designates a particular view as indicated. In deriving these profiles, the film records were projected onto an opaque surface with grid markings identical to those on which the image of the subject had been superimposed on the monitor face. Using a framing projector, each film clip was processed frame by frame, and each excursion of the suit/body silhouette from the nominal position was traced onto the projected surface. The result was the cumulative space occupied by the suit/body for the entire donning sequence, each view separately. All runs for a given subject were combined and the profiles are presented in composite. The figures are in a true 8:1 scale and actual dimensions to be utilized in the second half of the study were derived by measuring directly from the drawings. By combining the separate views orthogonally, the three-dimensional geometry of the donning envelope may be recreated.

It will be noted that six separate profiles for each subject are presented —seated: front, side, and top; standing: front, side, and top. Standing and seated views were collated separately for the purpose of ascertaining and correcting for any gross changes in scale factor due to the shift in body position relative to the camera location during the donning process. As can be seen in Figure 8, the calibration curves for the cameras (a single camera was used alternately for top and side views), at a nominal lens distance of approximately 108" only slight changes in the scale factor result from fairly wide excursions from the median position. Nevertheless, correction factors were introduced to normalize the standing profiles to the established 8:1 ratio.

Separate presentation of the standing-sitting profiles has the additional advantage of helping to account for how the donning space is "spent" in separate phases of the donning sequence. This information can be utilized to assist in evaluating future prototype suits for donning space requirements relative to the MK IV suit.

One further aspect of the donning profiles should be noted. While it is helpful to know the precise shape of the donning contours, the tortuous patterns produced are difficult, if not impossible to utilize. Seen as dotted lines on each profile, then, is a smoothed, and regularly shaped geometric form established on the basis of all subjects and all trials considered in toto. These smoothed contours are felt to be a reasonable approximation of the raw profiles and were used as the nominal geometric form for Part II of this investigation.

PART II - VOLUMETRIC DETERMINATIONS

The second part of this study was aimed at determining the trade-off between donning volume and time, holding geometric configuration constant. It was hypothesized that subjects could accommodate preliminary restrictions in donning volume in two ways: by utilizing the available space more efficiently, and by exerting greater effort in the process. The effect would be to maintain a level response time comparable to the unrestricted condition and, at some point in the diminution of donning volume, time would rapidly peak to a maximum followed by the subject's inability to complete the donning cycle. Within the limits of

available time and funds, an attempt was made to determine energy expenditure along with donning time. The measures employed, however, were too crude to be meaningful in this context. Patently, future studies of this kind should include a refined measure of work output.

Apparatus

The apparatus utilized in Part II was identical with that of Part I with the exclusion of photographic recording of the donning sequences.

Subjects

The same subjects were utilized with the exception of subject L, a 5th percentile subject, who was no longer available. At this stage of the investigation it was impracticable to obtain a replacement subject of the same qualifications. The results of this study phase are, thus, based on two 95th percentile and one 5th percentile subjects. It seems reasonable to assume that any volume adequate for a 95th percentile subject will be adequate for a 5th percentile subject.

Procedure

The same experimental procedure was used in Part II insofar as suit preparation, pre-don configuration, donning sequence and completion criterion were concerned. In Part II, however, the V.C. apparatus had been reconfigured to conform to the unrestricted geometry established in Part I. Subsequent to each donning trial for a given subject, the V.C. was reduced in internal volume by approximately two inches along each diameter towards the seat reference point (a reference point located at the intersection of the seat back and the seat bottom midway between the sides). The volume was systematically reduced until the subject was completely retained in the sitting position with knees, head, and shoulders touching the plastic plates of the capsule while in the resting position. It was felt that, though there may have been a possibility of the subjects' successfully donning in a still smaller volume, further reduction was meaningless for practical design considerations. At this point the donning sessions were ended.

It should be noted that the V.C. did not reach the starting configuration for the 5th percentile subject until after the 95th percentile subjects had gone through two reductions (their third trial). This may be seem more clearly in Figures 9 and 10.

RESULTS AND DISCUSSION

Table III presents the summarized results of Part II. The second column indicates which of the subjects participated in each reduction configuration (subjects M and B are 95th percentile subjects; subject C is 5th percentile). The numeral in subscript by each subject's initial indicates which step reduction that run represents for the particular subject. Column V_t is the calculated internal volume of the capsule for that run. T_a is the absolute donning time for each subject and ΔT is the increment in donning time over base time. Although no statistical analysis was attempted on this data involving so small a number of subjects, inspection of the trend tends to lend support to the original

hypothesis. Figures 9 and 10 illustrate the data of Table III in graphic form. As predicted, subjects were actually able to accommodate severe reductions in donning volume with little or no penalty in donning time. All subjects showed their greatest increase in donning time when the volume was decreased to between 25.9 and 28.6 ft^3, regardless of percentile. Subject M showed an abnormally large increment in donning time between the unrestricted condition and the first volumetric condition. Ideally, no volumetric restriction should have occurred between these two conditions; i.e., the first volumetric configuration of the V.C. was merely a reorientation of the panels to conform to the geometry described by the subject himself in Part I of the study. The unexpected donning time increment exhibited by subject M is felt to be accountable to a change in suits which occurred at this point in the study and which was due to a broken gusset zipper in the original suit. Subject M complained of excess bladder in the second suit during subsequent donning sessions. Nevertheless, it was the only suit available which would come close to fitting this subject. The increase in time which can be attributed to the ill-fitting suit is approximately three minutes. If subject M's times are all reduced by a three minute correction, his curves on Figures 9 and 10 very closely approximate those of his counterpart 95th percentile subject B.

Composite plots of each view of the capsule contours for each successive volumetric reduction are shown as Figures 11a - 13c. These figures are in a true 8:1 scale and actual dimensions may be derived by direct measurement from the plots. Graphic comparisons of each volumetric reduction may be made view for view by inspections of the plots. As can be readily seen, each reduction contour does not conform entirely to the original geometry, even though every effort was made to keep geometry constant. This was due to the characteristics of the V.C. which made it difficult to achieve a curvilinear contour using flat plates, especially so when the volumes become quite small.

Altogether, there were eight volumetric configurations utilized in Part II; however, each subject participated in no more than five. This is attributable to the fact that some subjects, due to the size of certain body features, reached an end point in some or all dimensions earlier than others. As a consequence, some reduction configurations (c.f., Column 1, Table III) will pertain to only one subject, some to two, and some to all three (c.f., Column 2, Table III). The subscript by the subject's initial indicates which trial a given reduction is for that subject. This same convention is observed in identifying the successive reduction contours in Figures 11a - 13c; i.e., the number of a given reduction profile on a particular figure refers to the subject's own sequence rather than the general sequence. The reader may refer back to Table III to ascertain the respective time factors and envelope volume for the reduction trial in question. The final datum point in each subject's curve (his final run) relates to a reduction of volume entirely to the sitting position. From Figures 11a - 13c it can be seen that the contour of the envelope for this last run is considerably different from the preceding contours. The reason for this difference is that the sitting geometry, as determined in Part I, is notably different from the standing geometry. Further, once the subject reached a limit laterally, these dimensions remained fixed while the overhead alone was reduced to the sitting configuration.

CONCLUSIONS

The geometry of the donning envelope is strikingly consistent from subject to subject for the MK IV full pressure suit. To the extent that the MK IV or a similar suit is concerned, the smooth contours in Figures 4a - 7f could be utilized for human factors input to the design of workplace layout in vehicles where suit donning is a consideration. This, of course, assumes a rigid enclosure; were it otherwise, the geometry of the enclosure would be of lesser import. Should it be desirable to acquire small increments of space near the subject, but external to the donning envelope (for placement of discrete controls, instruments, etc.), designers may refer to the raw contours of Figures 4a - 7f to find common areas of exclusion.

With respect to minimal volume, operational considerations must dictate a criterion, relative to time available, space available, and allowable energy expenditure. From this study, it appears that the best achievable donning time for the suit used (with unlimited volume) approaches 5 minutes, depending on the donner's proficiency. From the curves of Figures 9 and 10 it appears that an <u>optimal</u> donning volume would be between 31.5 and 36 cubic feet (distributed according to the established geometry). This represents a considerable saving in volume over the unrestricted condition with little or no penalty in donning time. This optimal volume, of course, fails to take into account the work output exacted by such a volumetric reduction.

It was mentioned at the outset that this study was conducted with certain assumptions in mind. In may be well to list these so that, if eventually some are found in gross error, the results may be interpreted accordingly.

1. Crewmen will be required to don the suit unassisted;

2. Crewmen will be enveloped independently in a rigid enclosure;

3. Crewmen will have no concurrent responsibilities while donning;

4. As long as the subject can don within a reasonable period of time, no limit to work output is established;

5. The suit will be similar in donning characteristics to the Navy MK IV suit;

6. Crewmen will don from sit-stand orientation (our data covers both sit-stand and sit only; however, if the donning takes place under zero gravity, the body orientation may be a moot point);

7. The undonned configuration of the suit will be arrayed on the deck as described in this study; associated portable life support equipment will be stowed external to the donning envelope;

8. The crewman will not be attached to the vehicle by biosensors, life support equipment, etc. (although to be maintained in the orientation of this study under zero-g conditions, some restraints will be required).

RECOMMENDATIONS

Within the limits described above, the conclusions drawn from this investigation are felt to be sufficiently reliable for design purposes. It is recommended that certain problem areas be given further consideration and perhaps investigation before drawing definitively from these results. Depending upon how radical the departure will be of future suits from the MK IV configuration, these suits should be subjected to similar investigation to establish the applicability of the MK IV results.

Since overstressing the crewman in the suit donning task is a condition to be avoided, it is considered vital to investigate the effects of systematic reductions in the donning volume on work output. It would then be possible to determine whether or not the subjects of this study were maintaining their donning time under severe restrictions in volume only through an extravagant and unacceptable expenditure of energy.

A conglomerate area which should receive additional attention is the location of the suit in the undonned configuration and related problems of using structural assists to simplify the donning process as well as the restraints which will be required for donning under zero gravity. As a point of departure, one might consider location of the basic suit in a slide-top recess below the feet which would provide out-of-the-way stowage for the garment while being readily available for donning. The recess would also provide additional donning volume for the crewman. The bootees of the suit could be mechanically or magnetically attached to the base of the stowage compartment so that once the crewman's feet were in place, he could release himself from his couch and continue donning, restrained from freely floating about the donning envelope without interference with the remaining donning sequence. Location of the gloves in a recess at elbow level would eliminate reaching; further, they could be attached in such fashion to aid in donning. The helmet, located in a recess overhead would be readily accessible. These design proposals are, of course, only a few of the many possibilities. They are mentioned merely as illustrative of the intimate relationship between suit stowage, donning, and associated restraints.

TABLE I

MORPHOLOGICAL DIMENSIONS OF SUBJECTS*

Subj.	Height		Sitting Height		Shoulder Breadth		Buttock-knee Length		Buttock-leg Length	
	Inches	%ile	Inches	%ile	Inches	%ile	Inches	%ile	Inches	%ile
M	70.9	63	37.4	84	20.7	99+	23.6	56	43.9	72
B	70.3	50	37.5	85	19.4	96	23.0	38	44.3	76
C	66.3	4	35.5	38	17.8	55	22.1	17	41.0	29
L	66.2	3	35.9	48	18.2	70	21.2	4	39.7	14

*c.f. Report NAMC-ACEL-437 "Compilation of Anthropometric Measures of U.S. Navy Pilots"

TABLE II

UNRESTRICTED DONNING TIMES (MIN:SEC)

	Subj.	Session 1	Session 2	Session 3	Mean
95th %ile	M	7:28	7:17	7:00	7:15
	B	5:41	5:05	--	5:23
5th %ile	C	12:05	8:21	9:38	10:01
	L	10:48	8:17	--	9:32

TABLE III

RESULTS OF VOLUMETRIC DETERMINATIONS

Reduc-tion	Subject Exposure	V_t (ft^3)	Donning Time (Min:Sec) T_a - Absolute Time M	B	C	ΔT - Time Increase M	B	C
1	M_1B_1	48.1194	10:39	6:03		3:24	:40	
2	M_2B_2	42.4340	10:41	6:00		3:26	:37	
3	$M_3B_3C_1$	36.1653	10:13	5:16	8:51	2:58	:07*	1:10*
4	M_4	31.5762	10:28			3:13		
5	B_4C_2	28.5926		8:30	12:08		3:07	2:07
6	M_5B_5	25.8741	14:54	8:13		7:39	2:50	
7	C_3	25.7356			12:37			2:36
8	C_5	22.4552			14:28			4:27

*Decrement in time from base

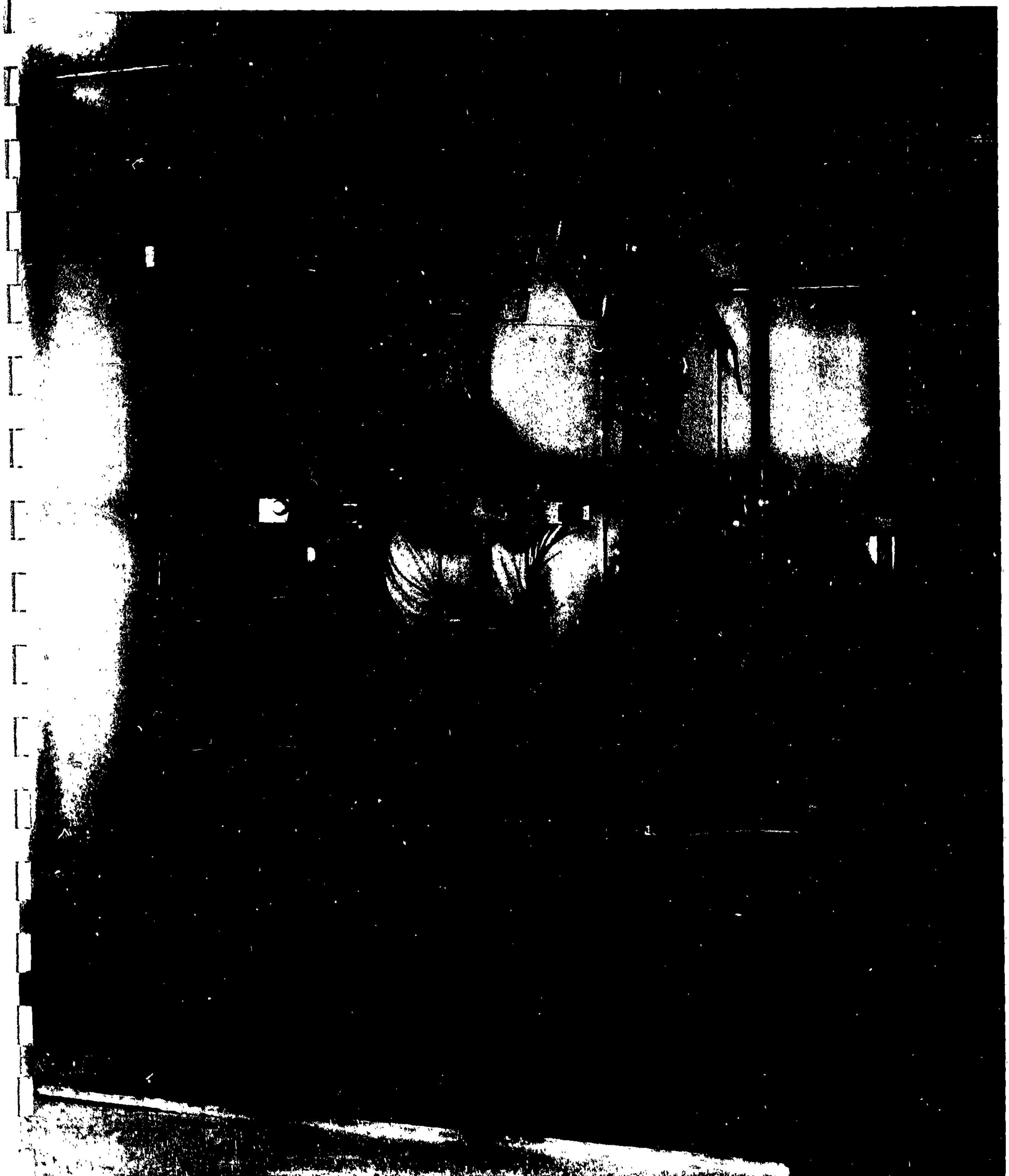

FIGURE 1

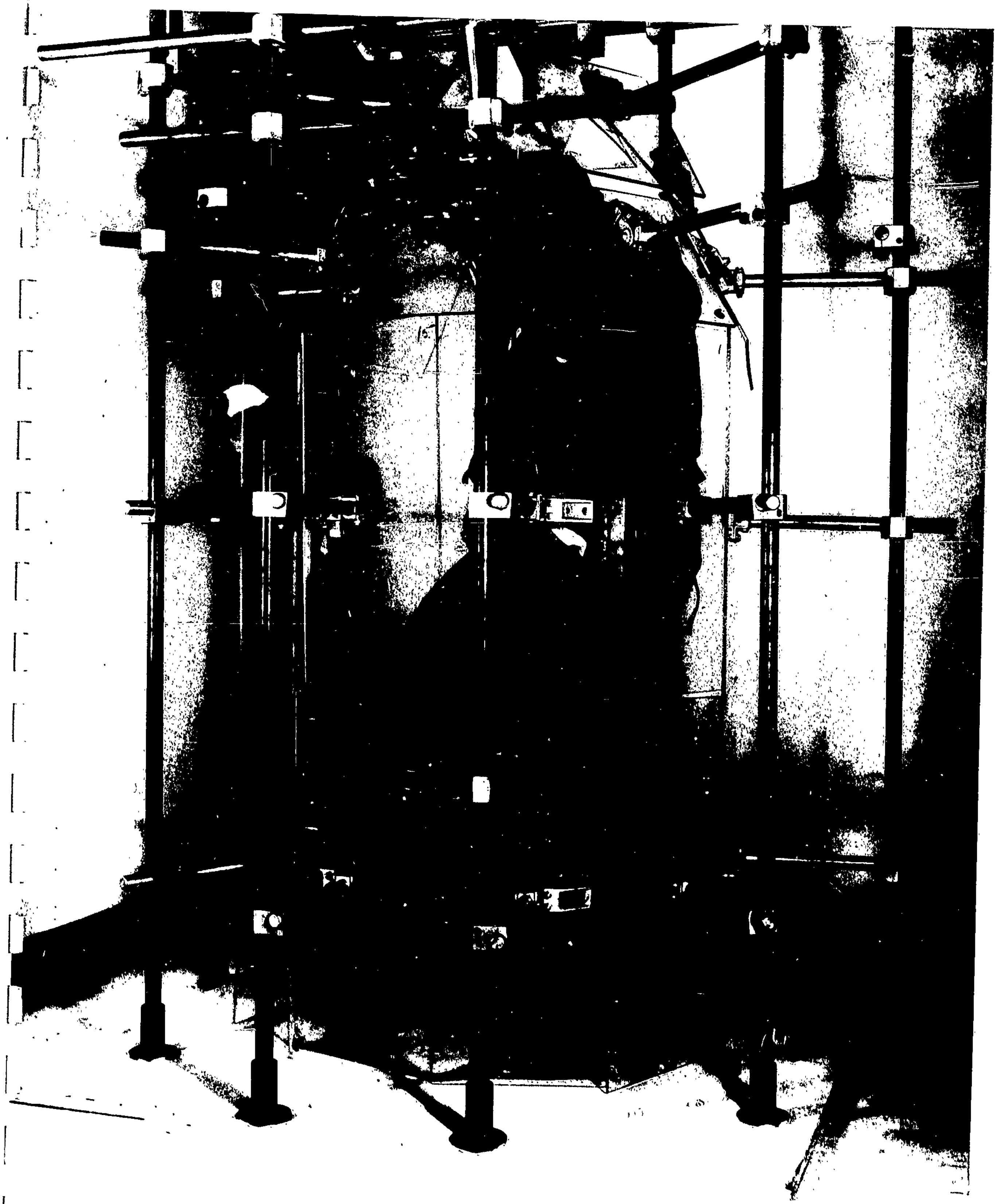

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FIGURE 3

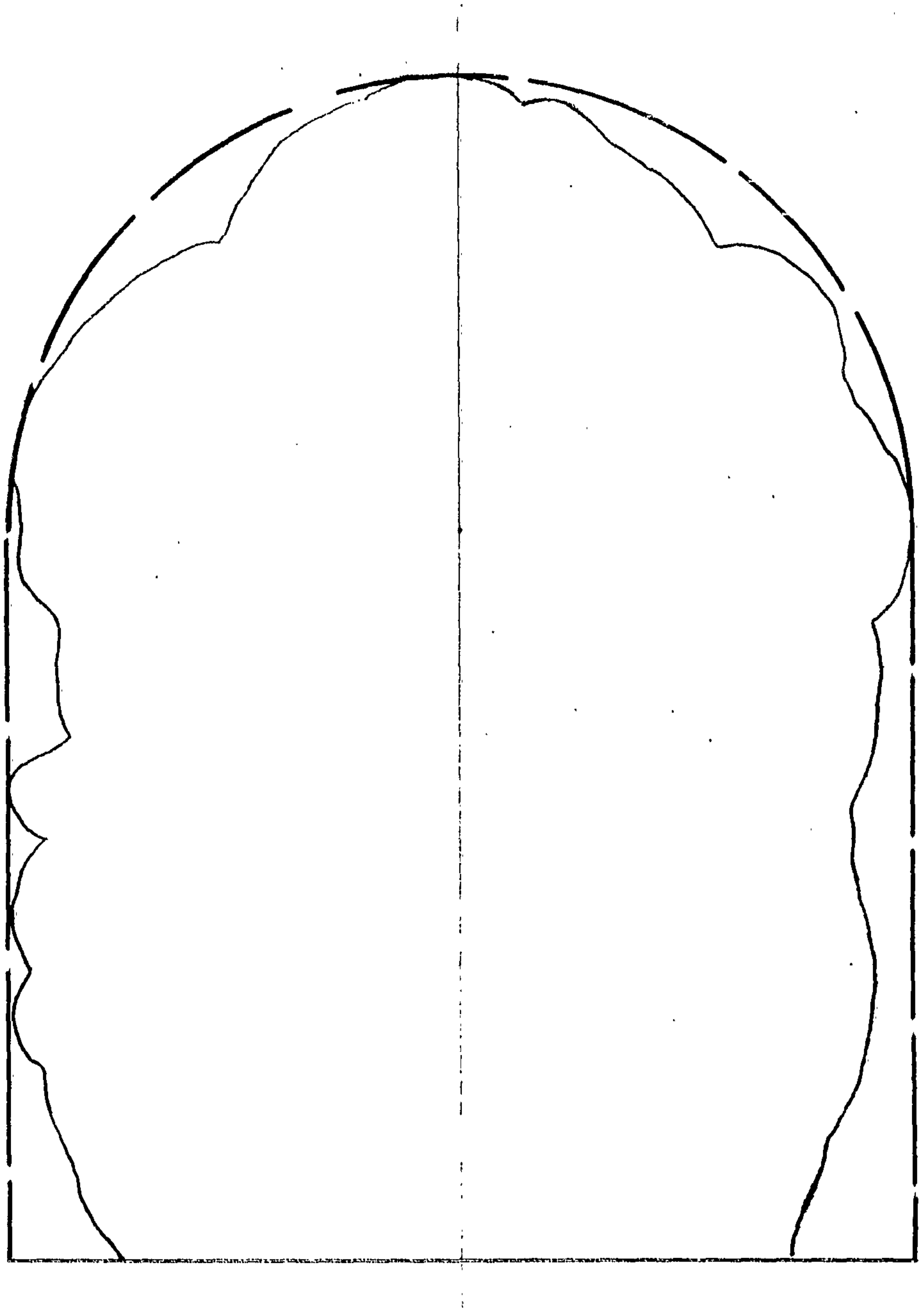

FIGURE 4a
SITTING FRONT
SUBJECT M - 95%ILE
SCALE 8:1

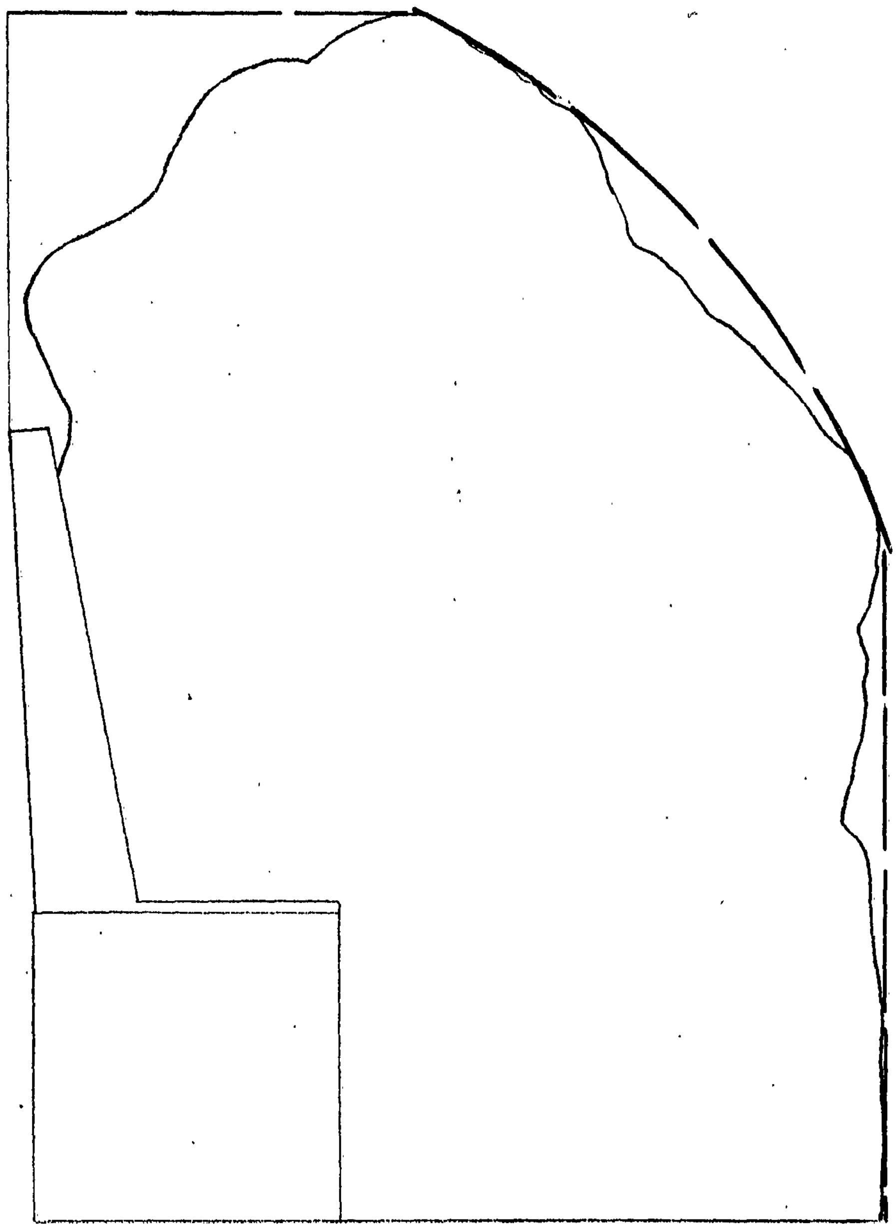

FIGURE 4b
SITTING SIDE
SUBJECT M - 95%ILE
SCALE 8:1

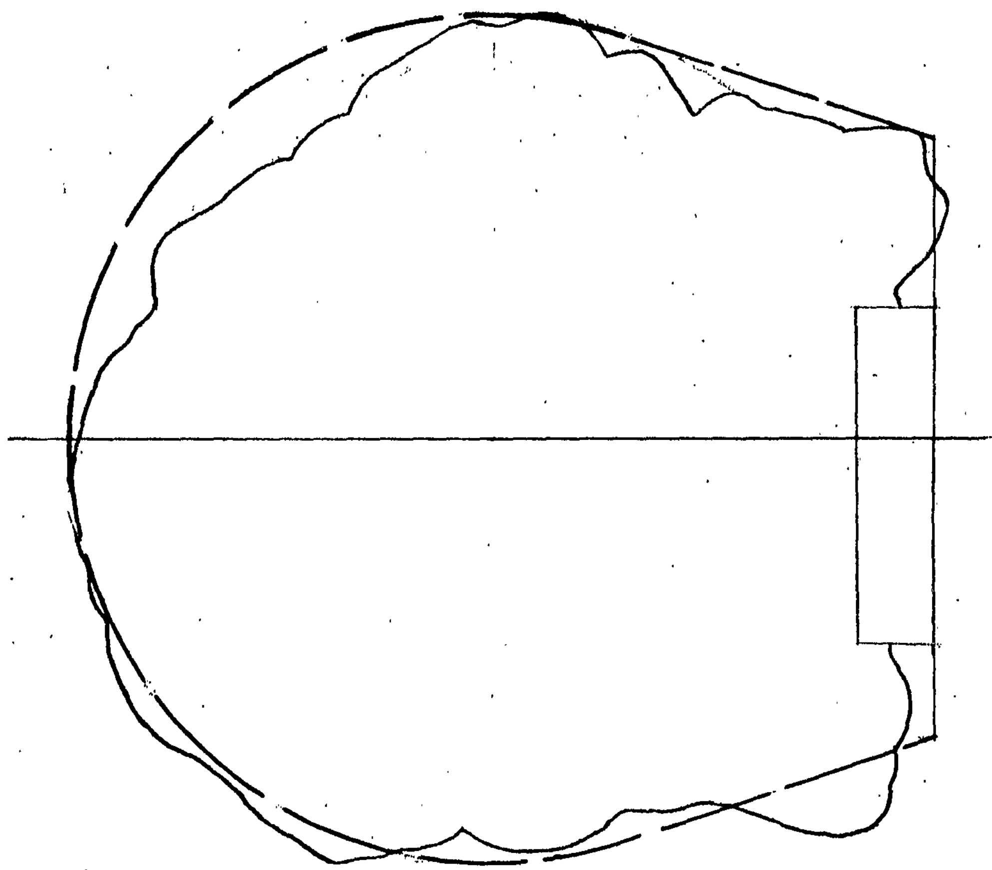

FIGURE 4c
SITTING TOP
SUBJECT M - 95%ILE
SCALE 8:1

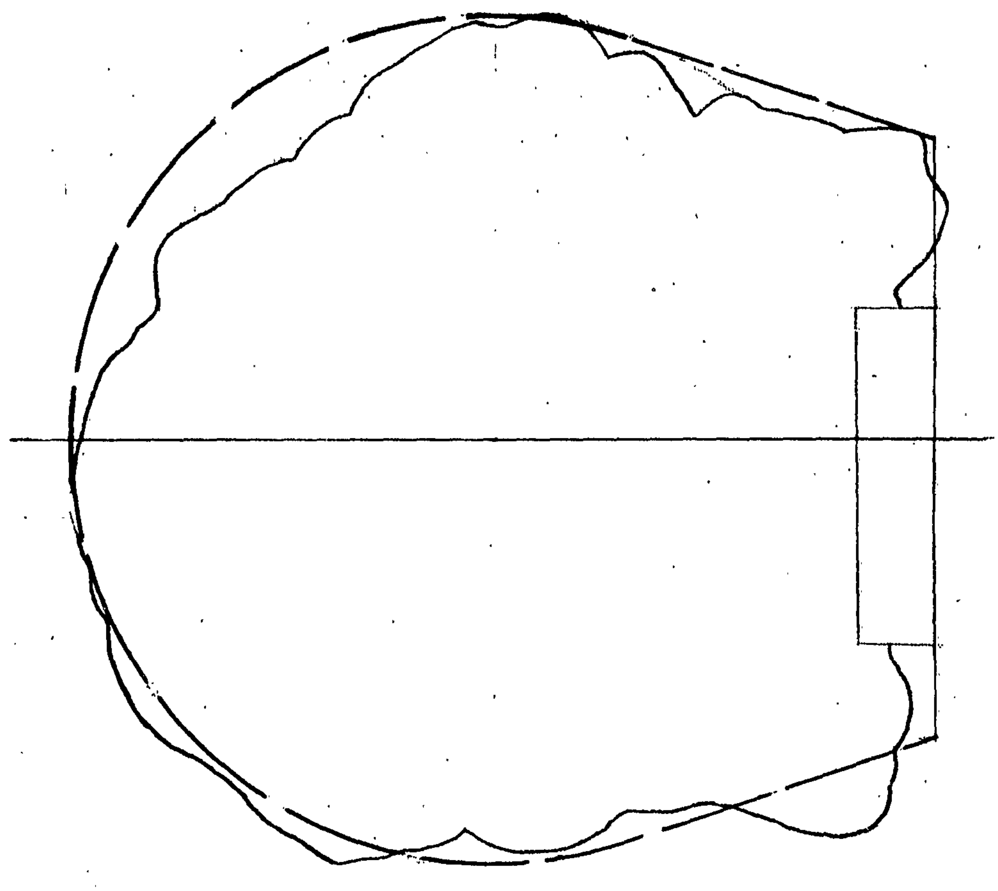

FIGURE 4c
SITTING TOP
SUBJECT M - 95%ILE
SCALE 8:1

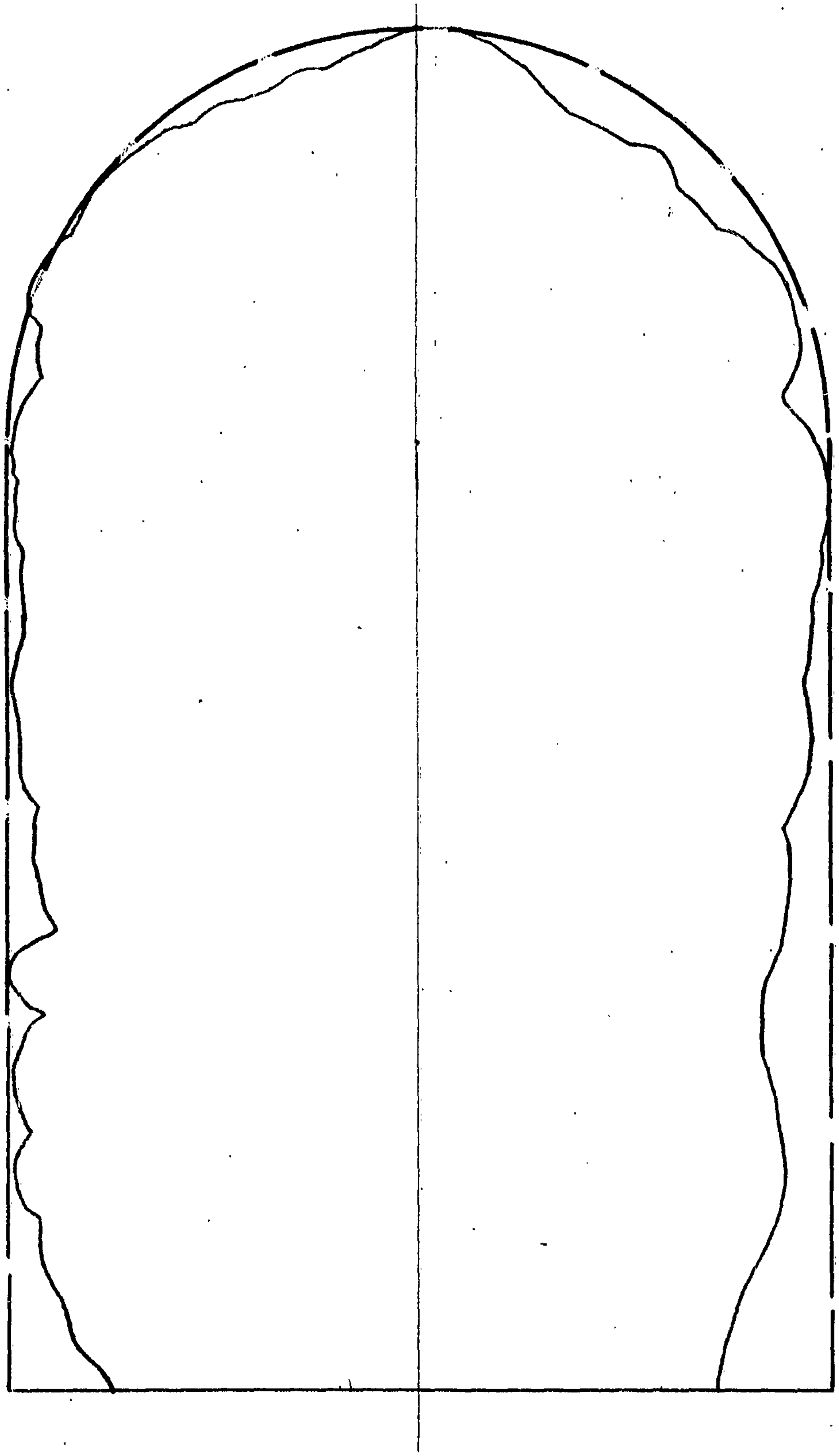

FIGURE 4d
STANDING, FRONT
SUBJECT M - 95%ILE
SCALE 8:1

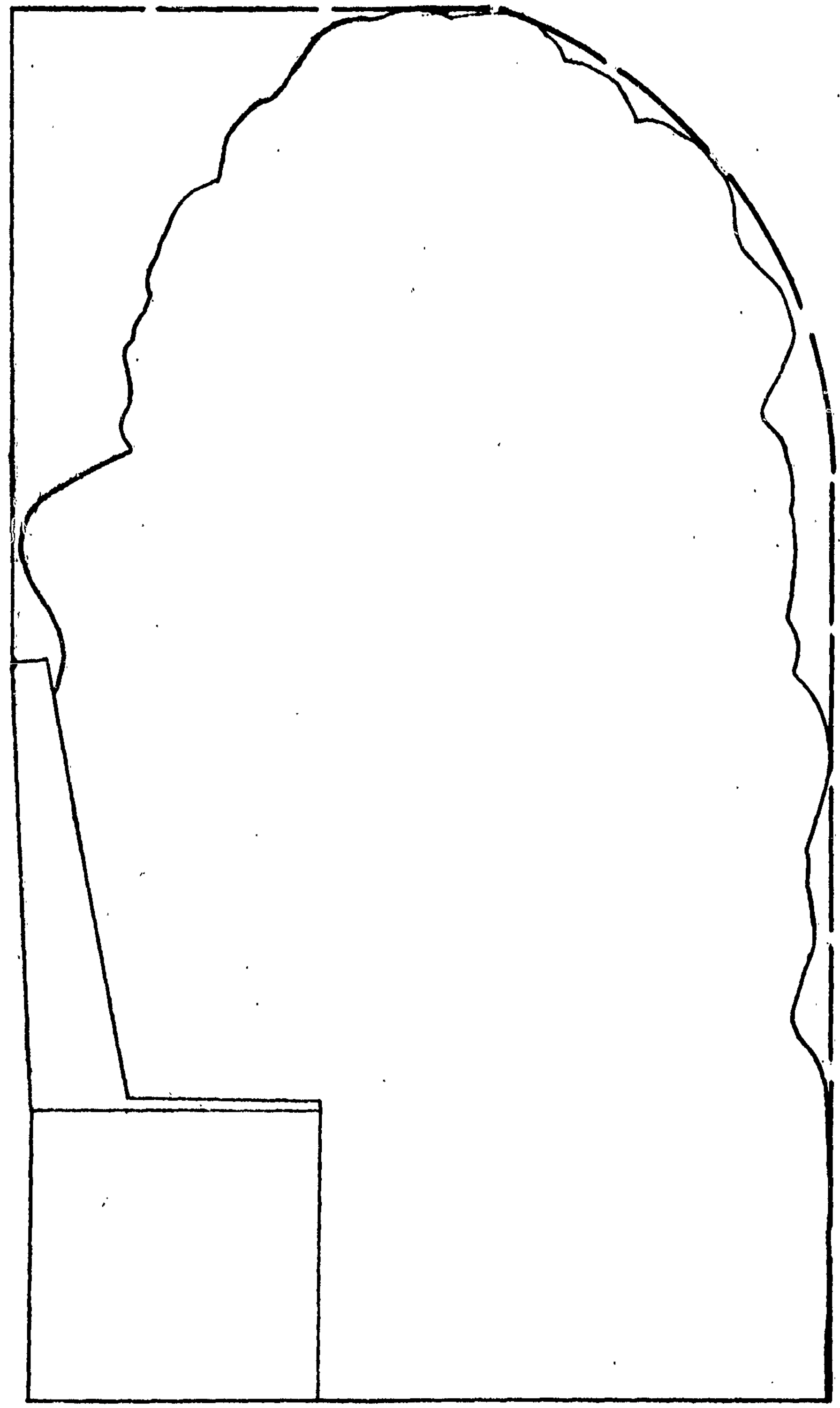

FIGURE 4e
STANDING SIDE
SUBJECT M - 95%ILE
SCALE 8:1

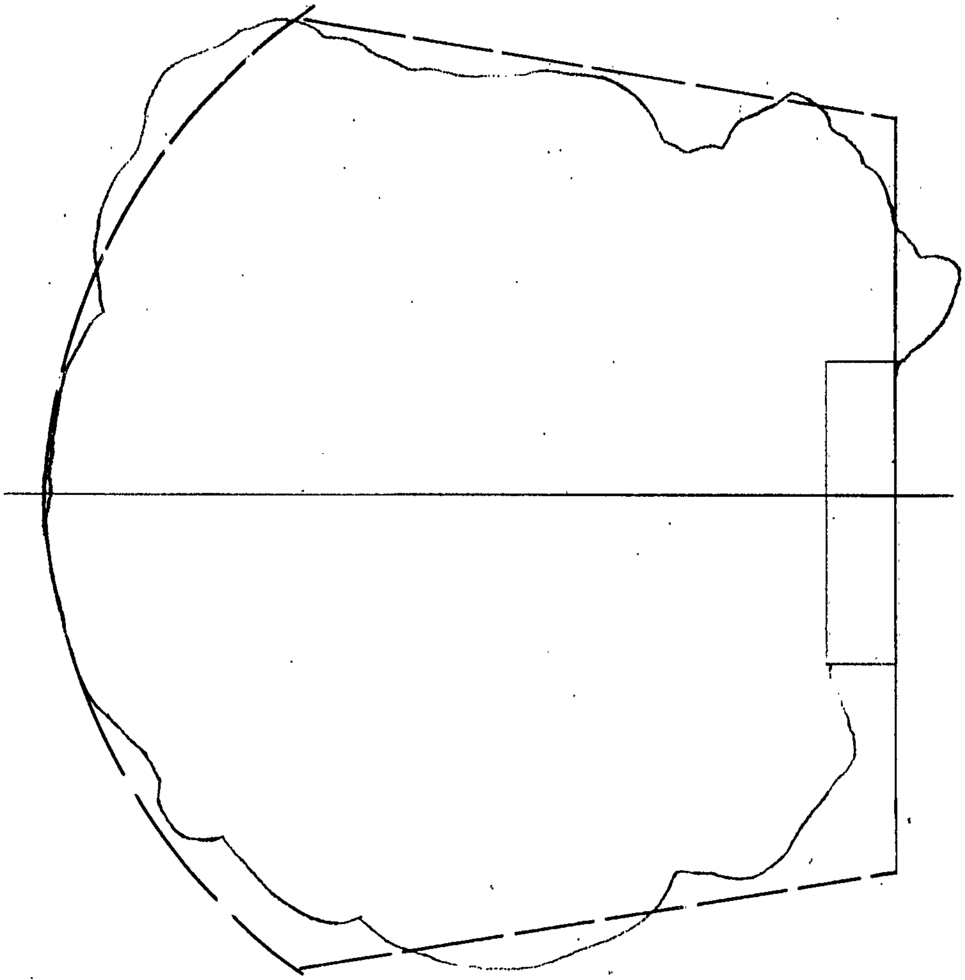

FIGURE 4f
STANDING TOP
SUBJECT M - 95%ILE
SCALE 8:1

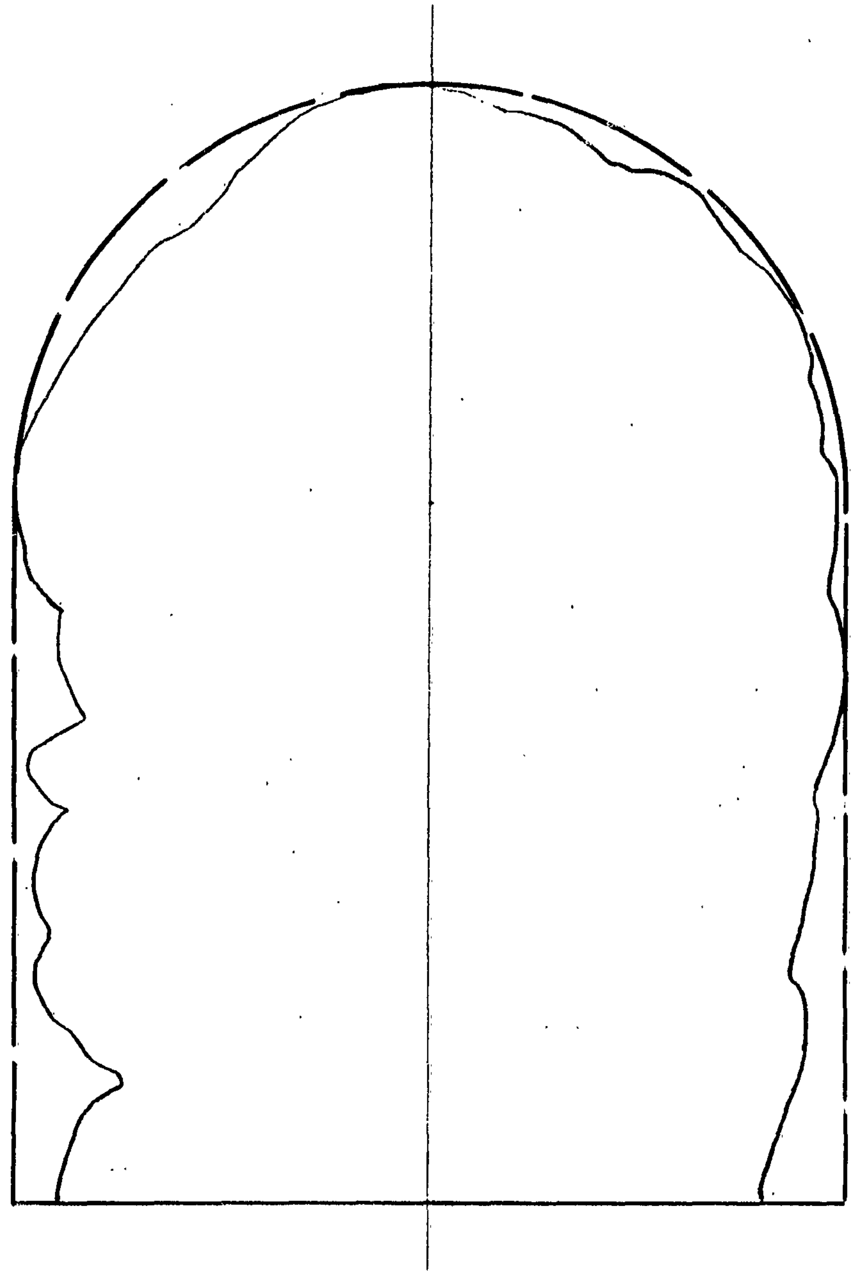

FIGURE 5a
SITTING FRONT
SUBJECT B - 95%ILE
SCALE 8:1

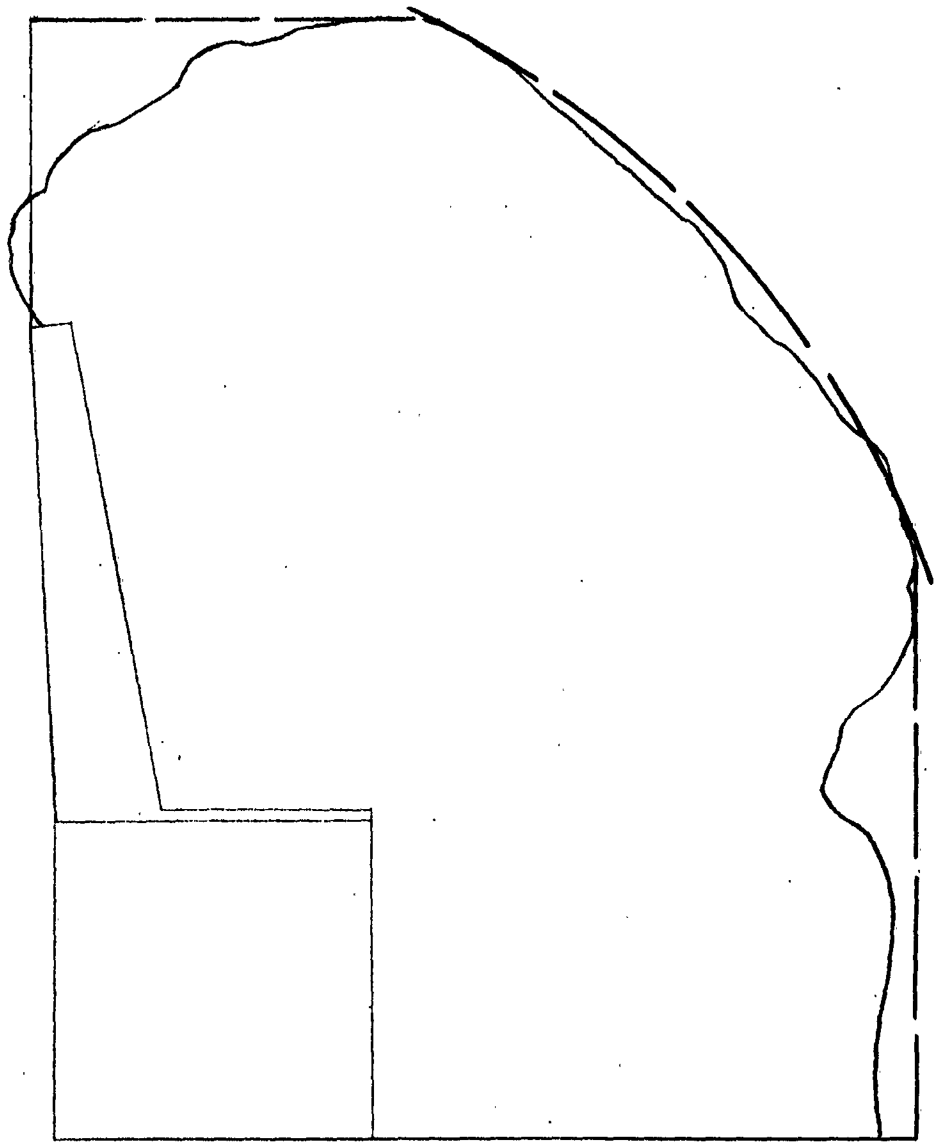

FIGURE 5b
SITTING SIDE
SUBJECT B - 95%ILE
SCALE 8:1

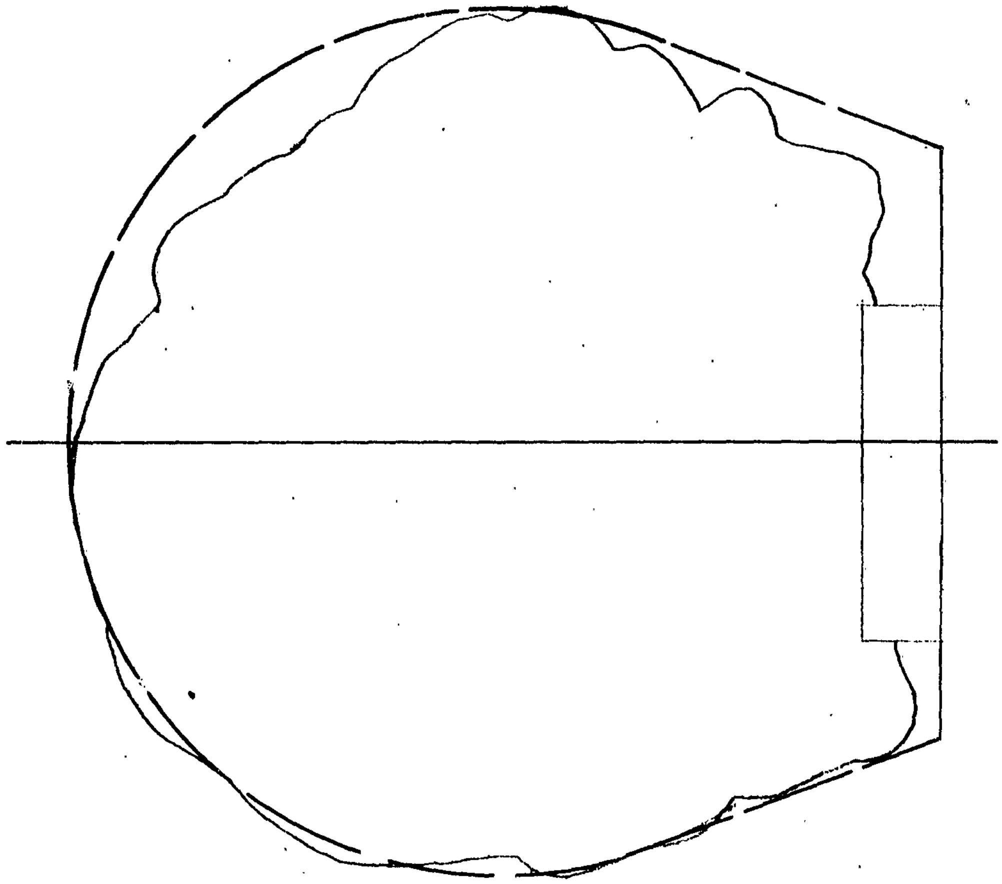

FIGURE 5c
SITTING TOP
SUBJECT B - 95%ILE
SCALE 8:1

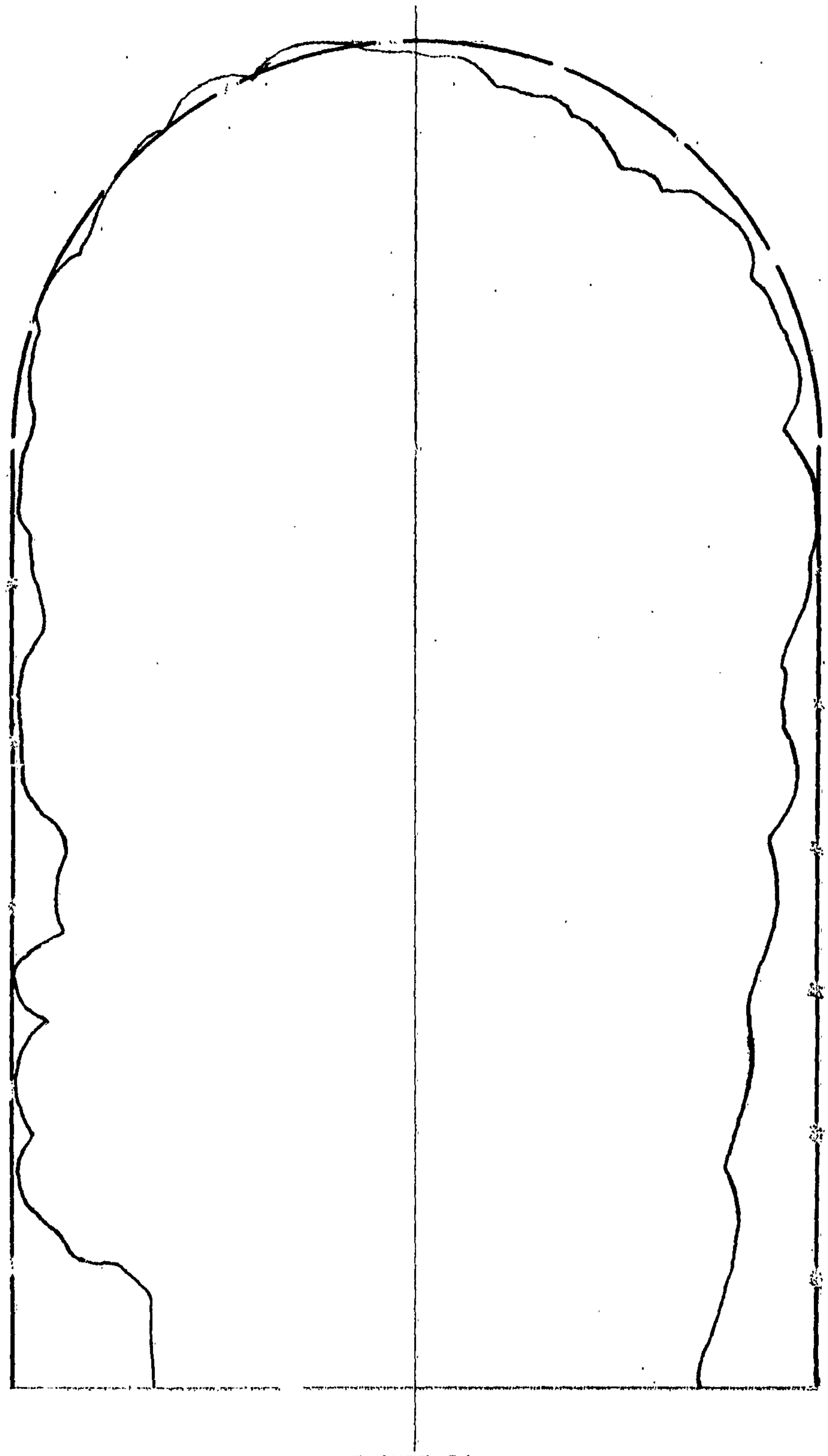

FIGURE 5d
STANDING FRONT
SUBJECT B - 95%ILE
SCALE 8:1

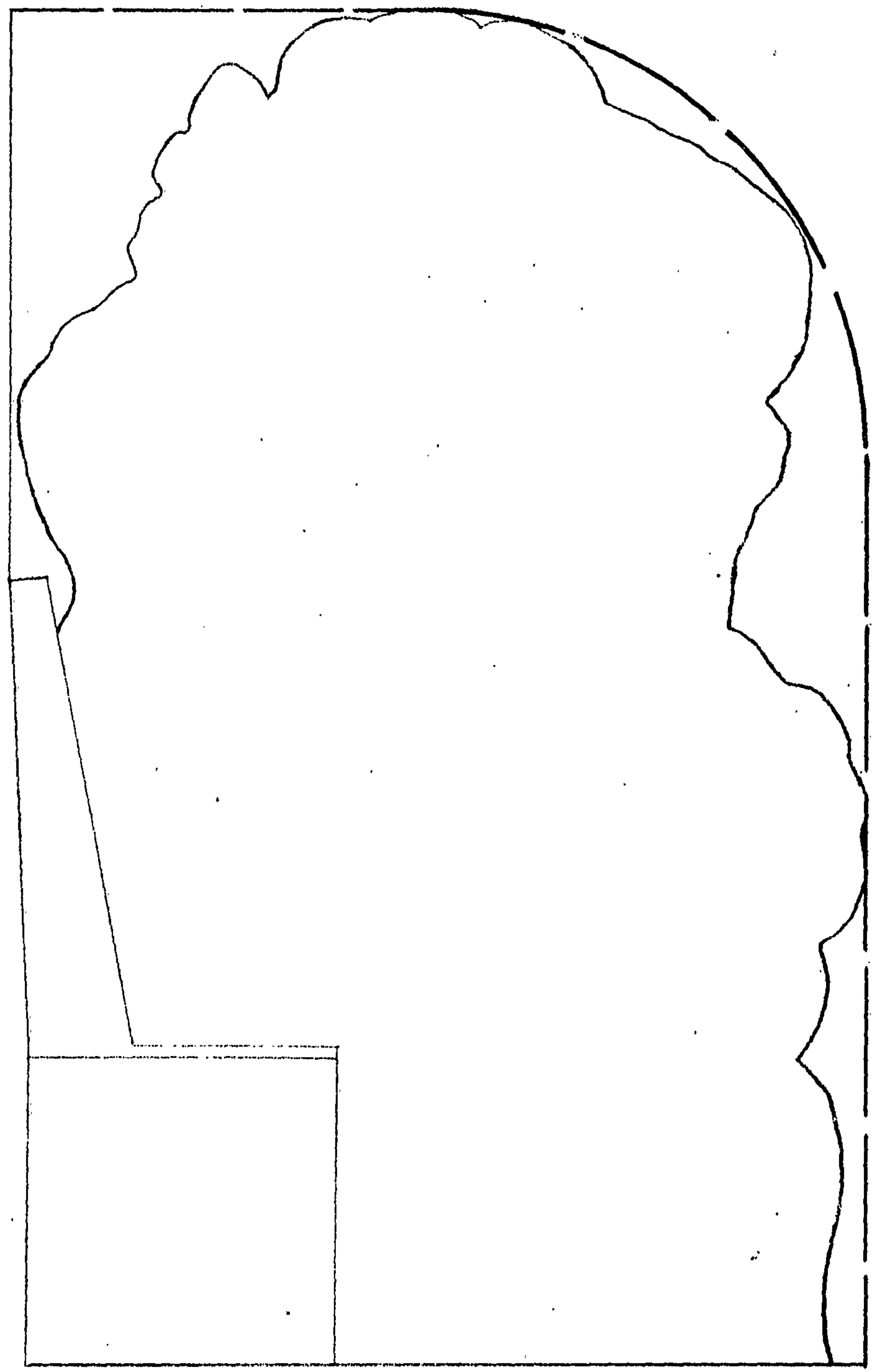

FIGURE 5e
STANDING SIDE
SUBJECT B - 95%ILE
SCALE 8:1

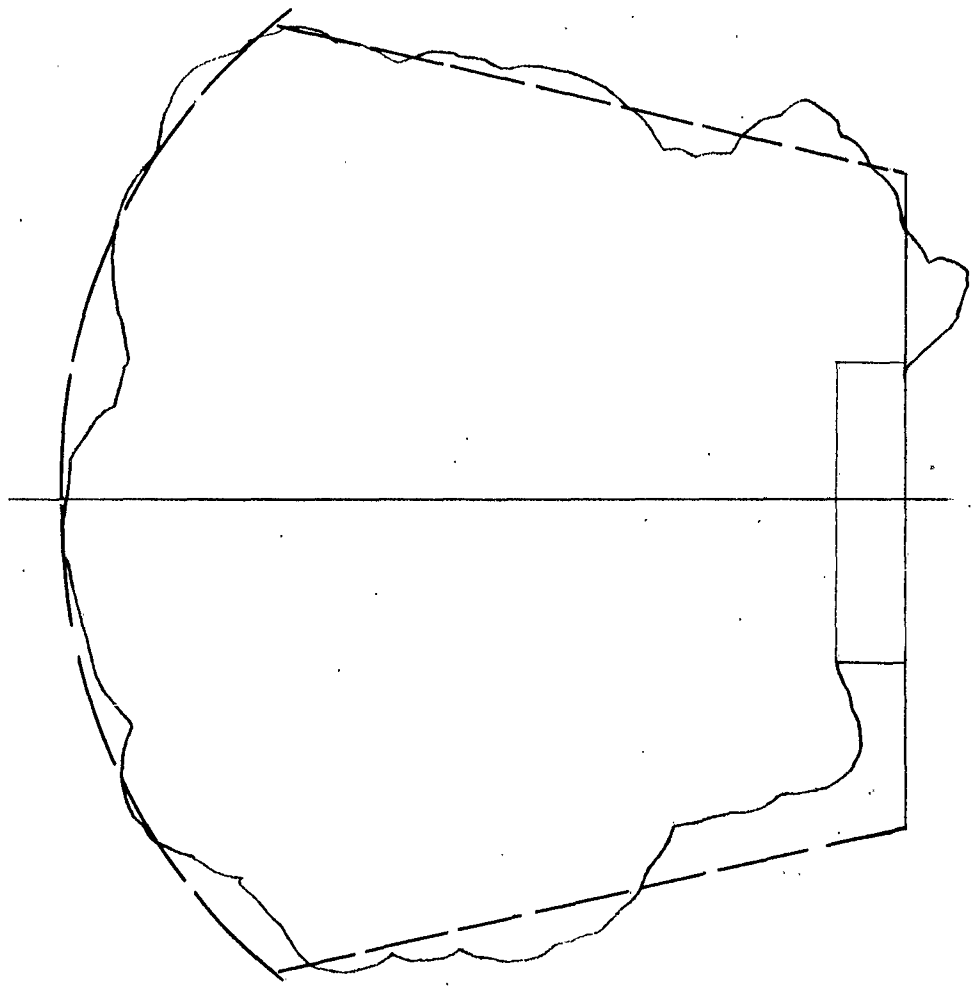

FIGURE 5f
STANDING TOP
SUBJECT B - 95%ILE
SCALE 8:1

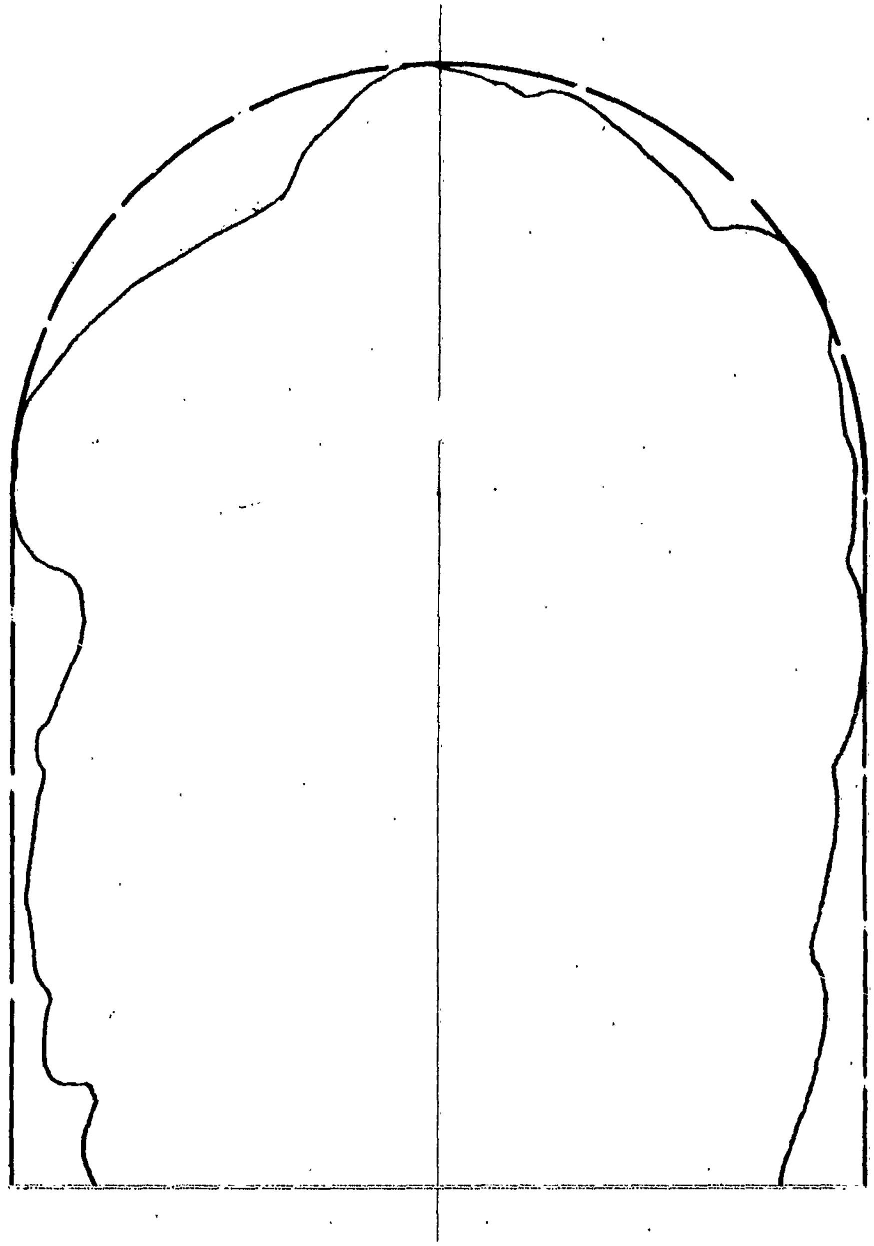

FIGURE 6a
SITTING FRONT
SUBJECT C - 5%ILE
SCALE 8:1

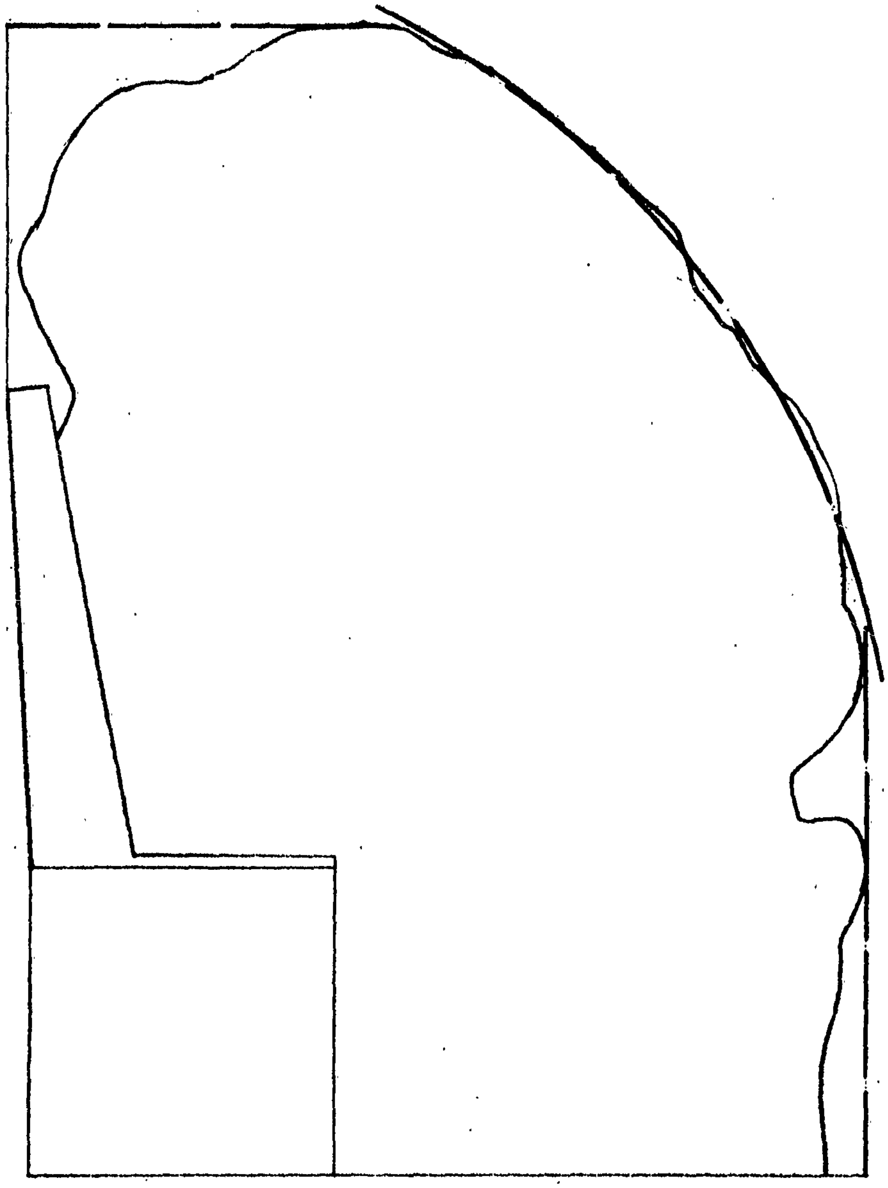

FIGURE 6b
SITTING SIDE
SUBJECT C - 5%ILE
SCALE 8:1

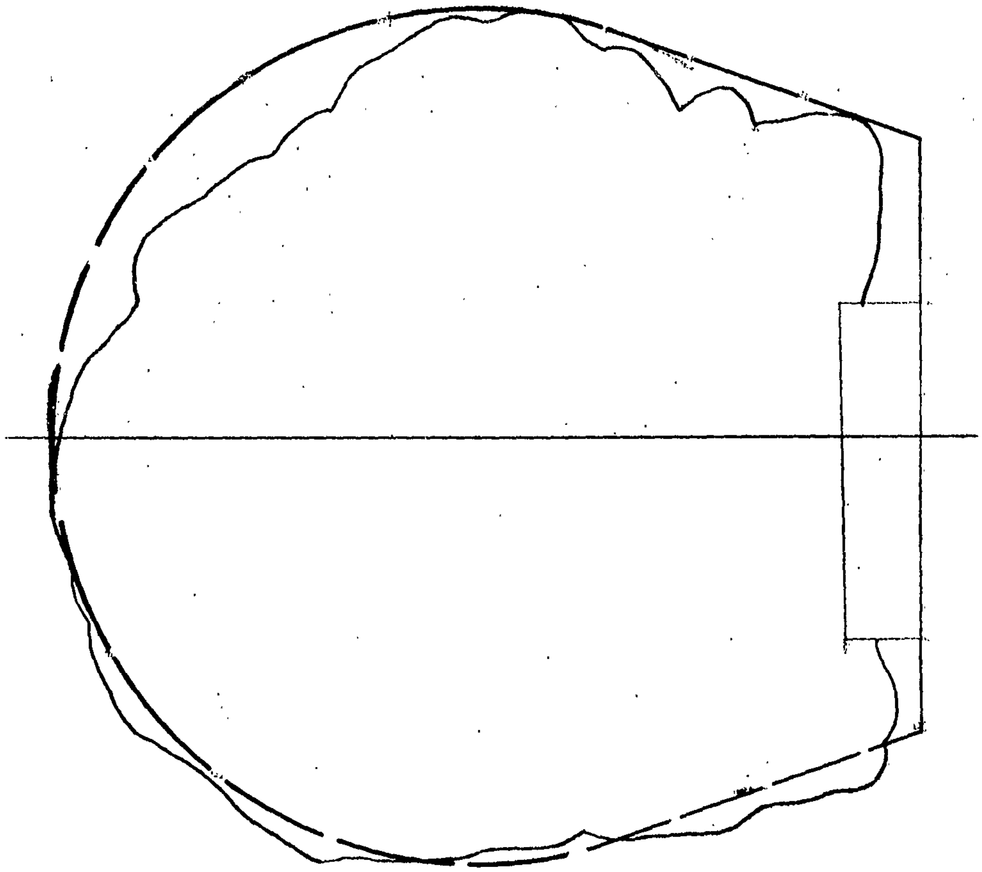

FIGURE 6c
SITTING TOP
SUBJECT C - 5%ILE
SCALE 8:1

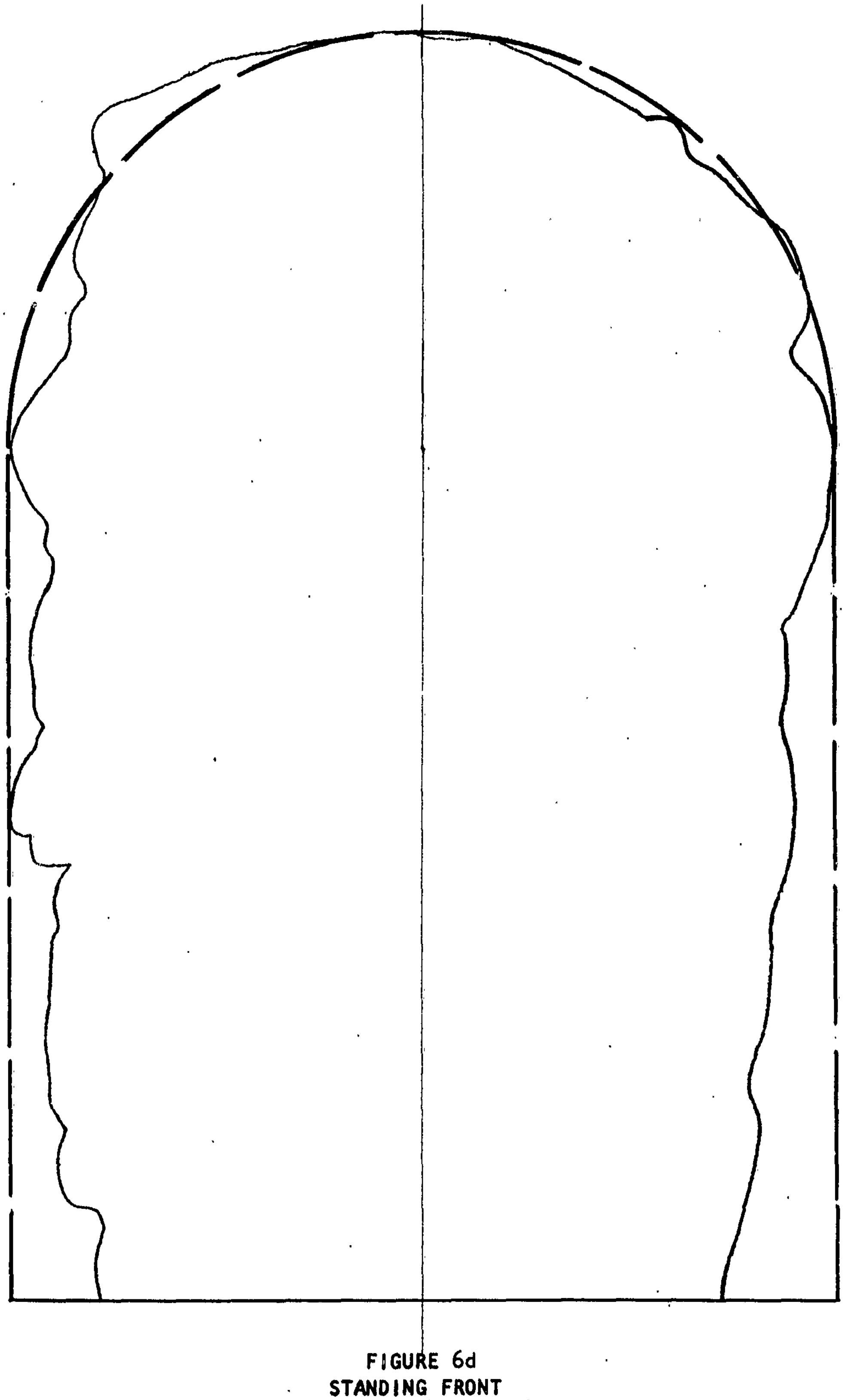

FIGURE 6d
STANDING FRONT
SUBJECT C - 5%ILE
SCALE 8:1

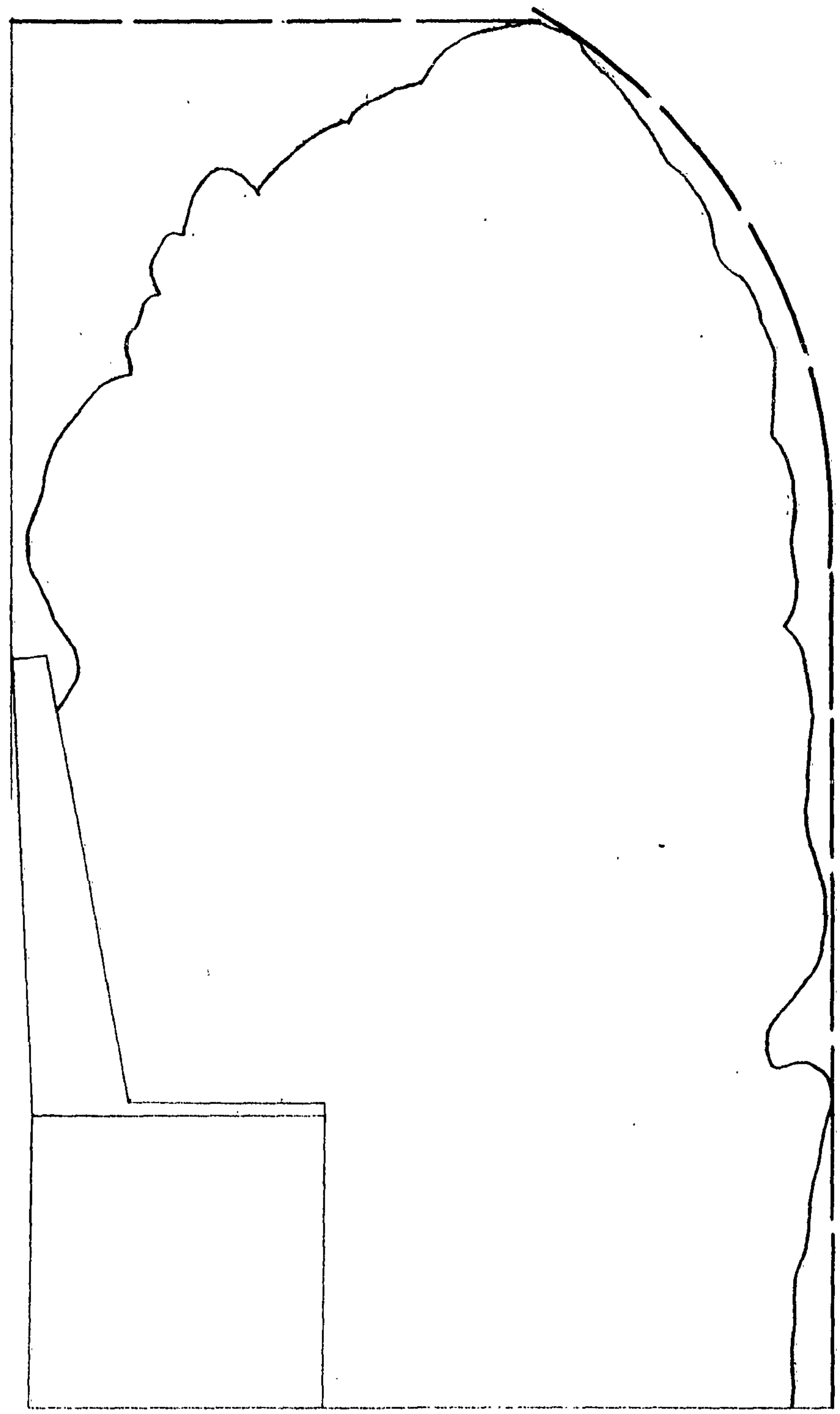

FIGURE 6e
STANDING SIDE
SUBJECT C - 5%ILE
SCALE 8:1

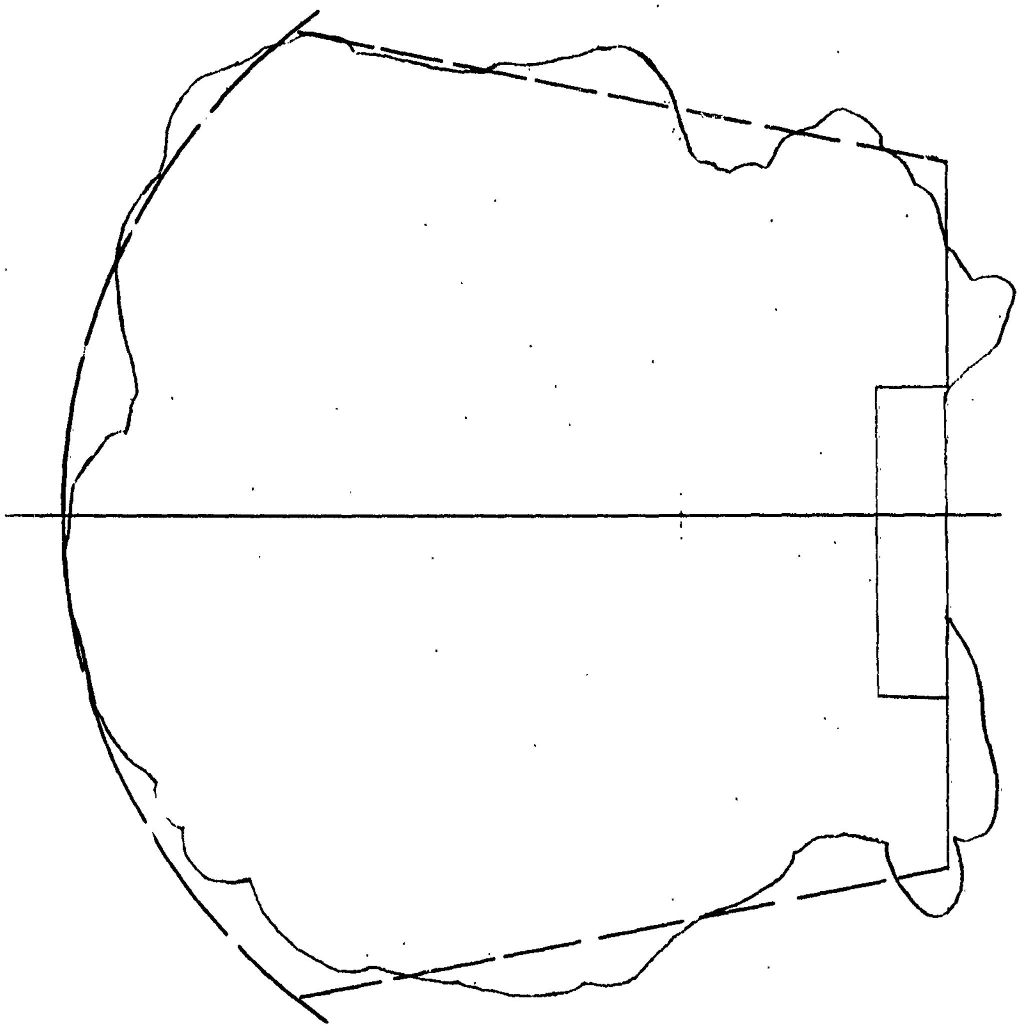

FIGURE 6f
STANDING TOP
SUBJECT C - 5%ILE
SCALE 8:1

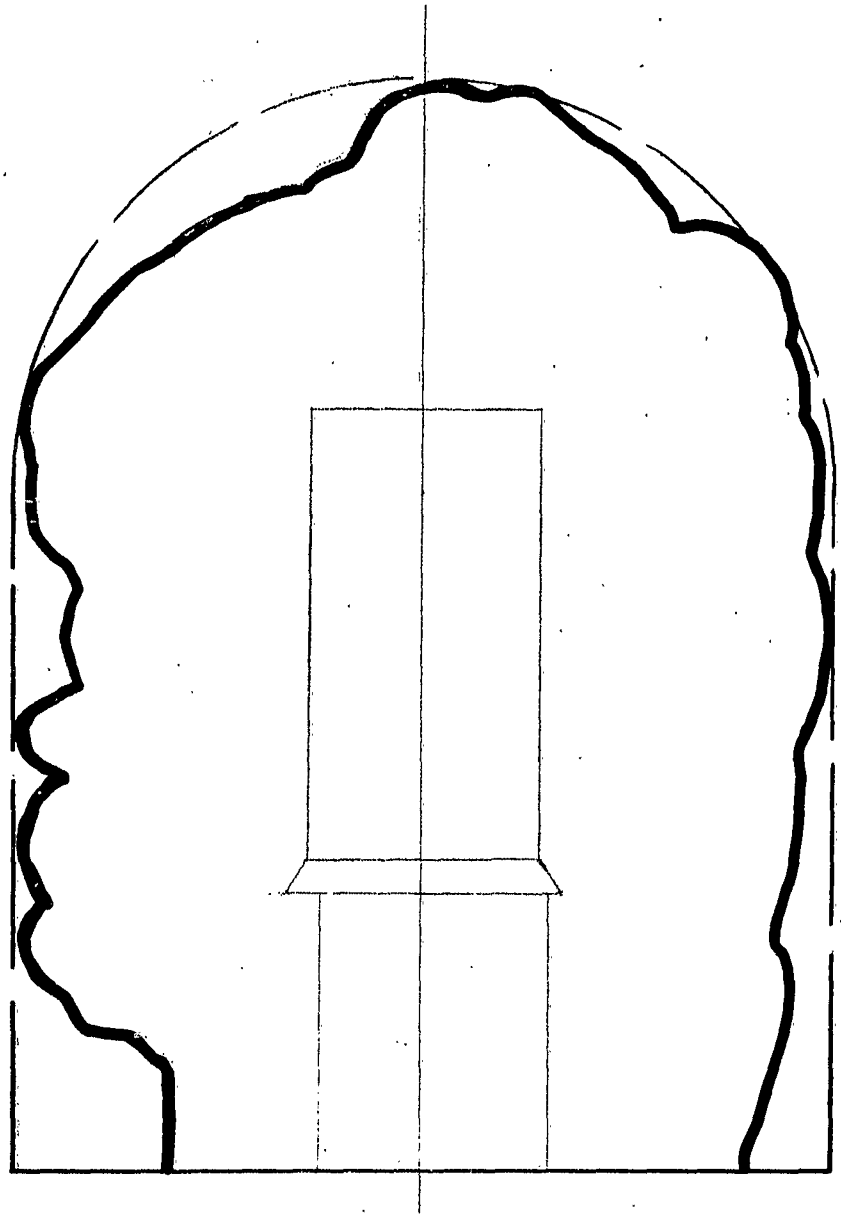

FIGURE 7a
SITTING FRONT
SUBJECT L - 5%ILE
SCALE 8:1

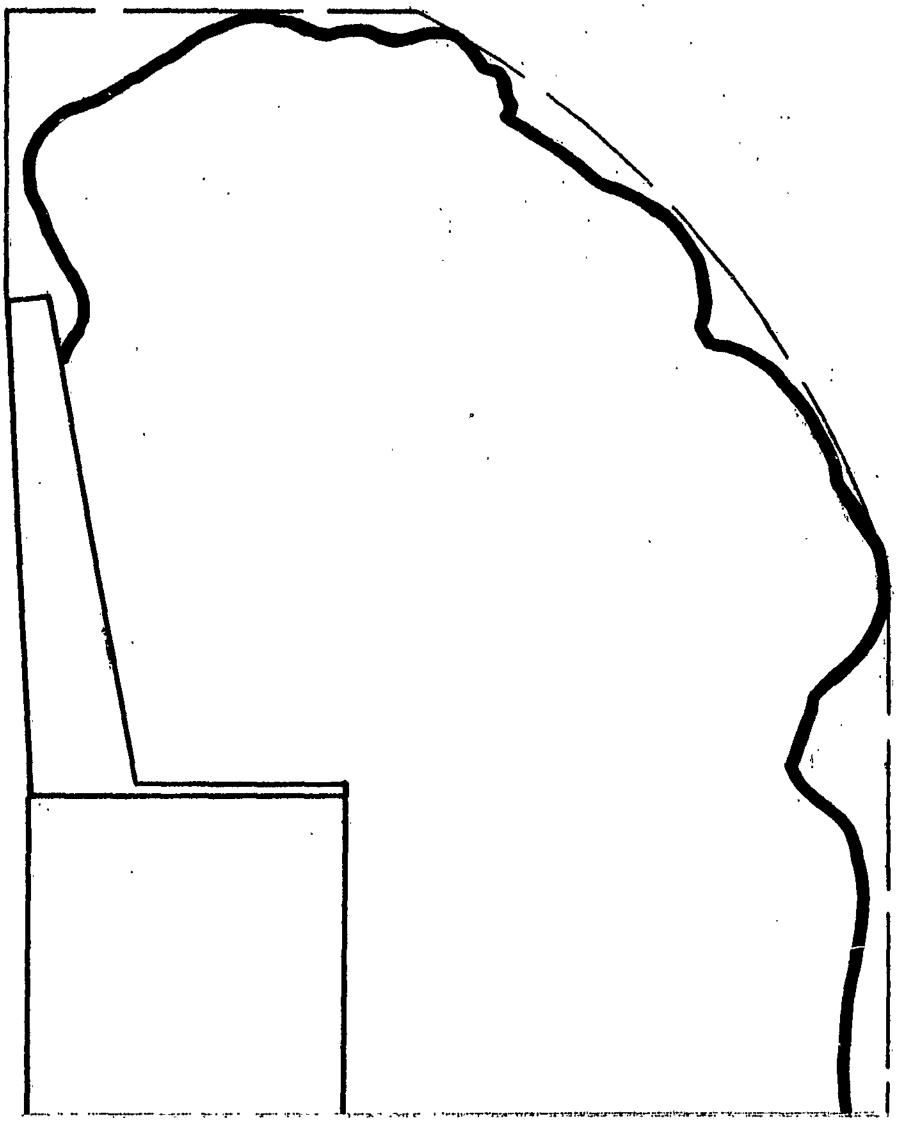

FIGURE 7b
SITTING FRONT
SUBJECT L - 5%ILE
SCALE 8:1

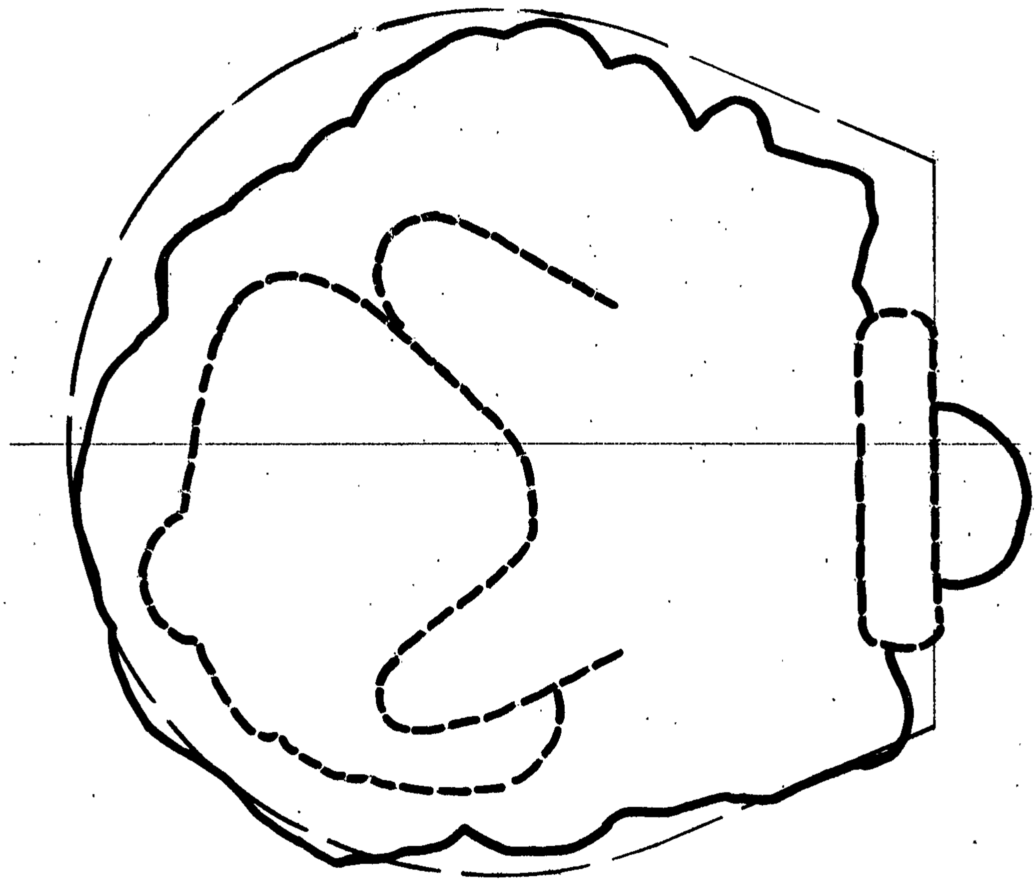

FIGURE 7c
SITTING TOP
SUBJECT L - 5%ILE
SCALE 8:1

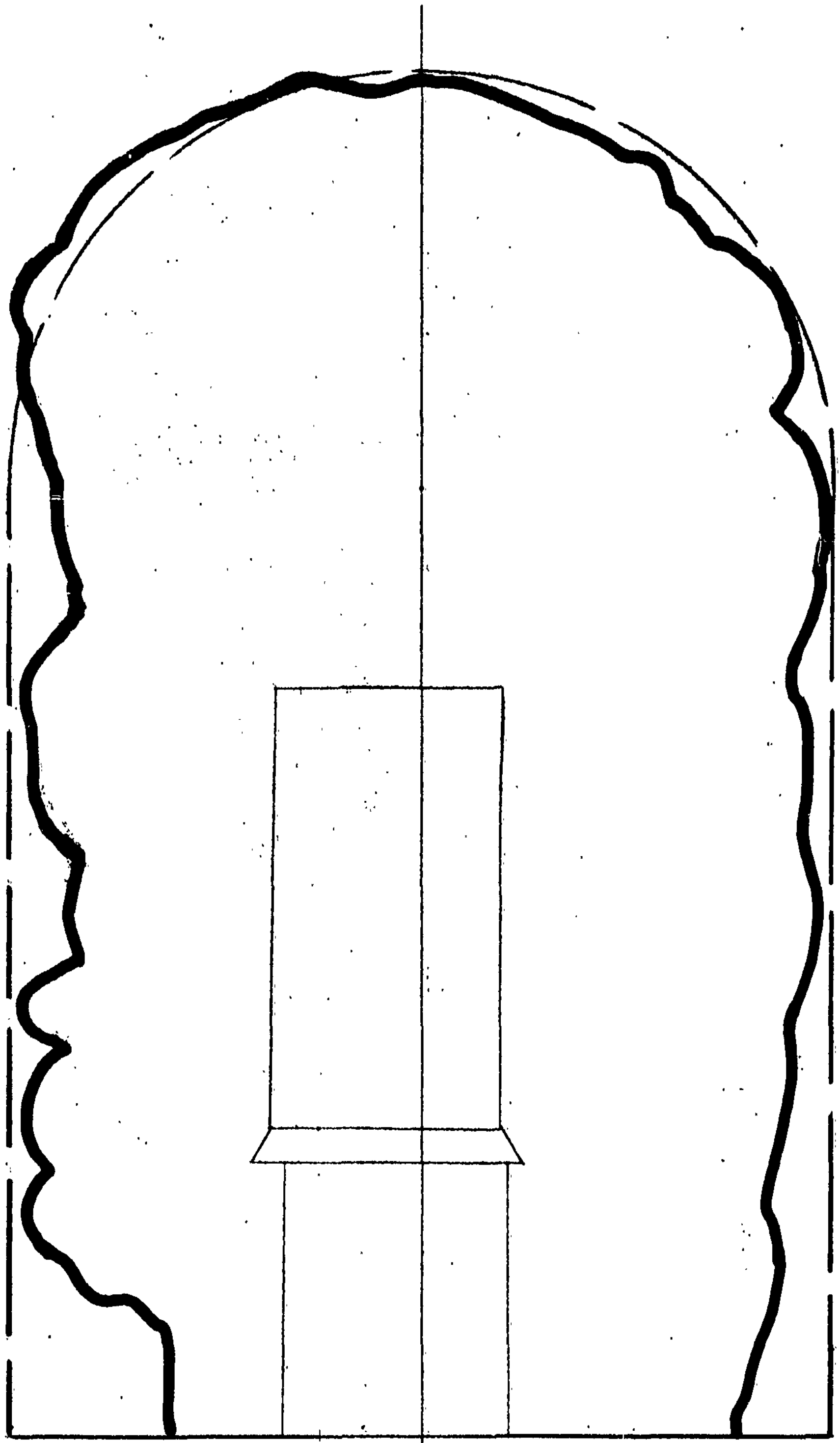

FIGURE 7d
STANDING FRONT
SUBJECT L - 5%ILE
SCALE 8:1

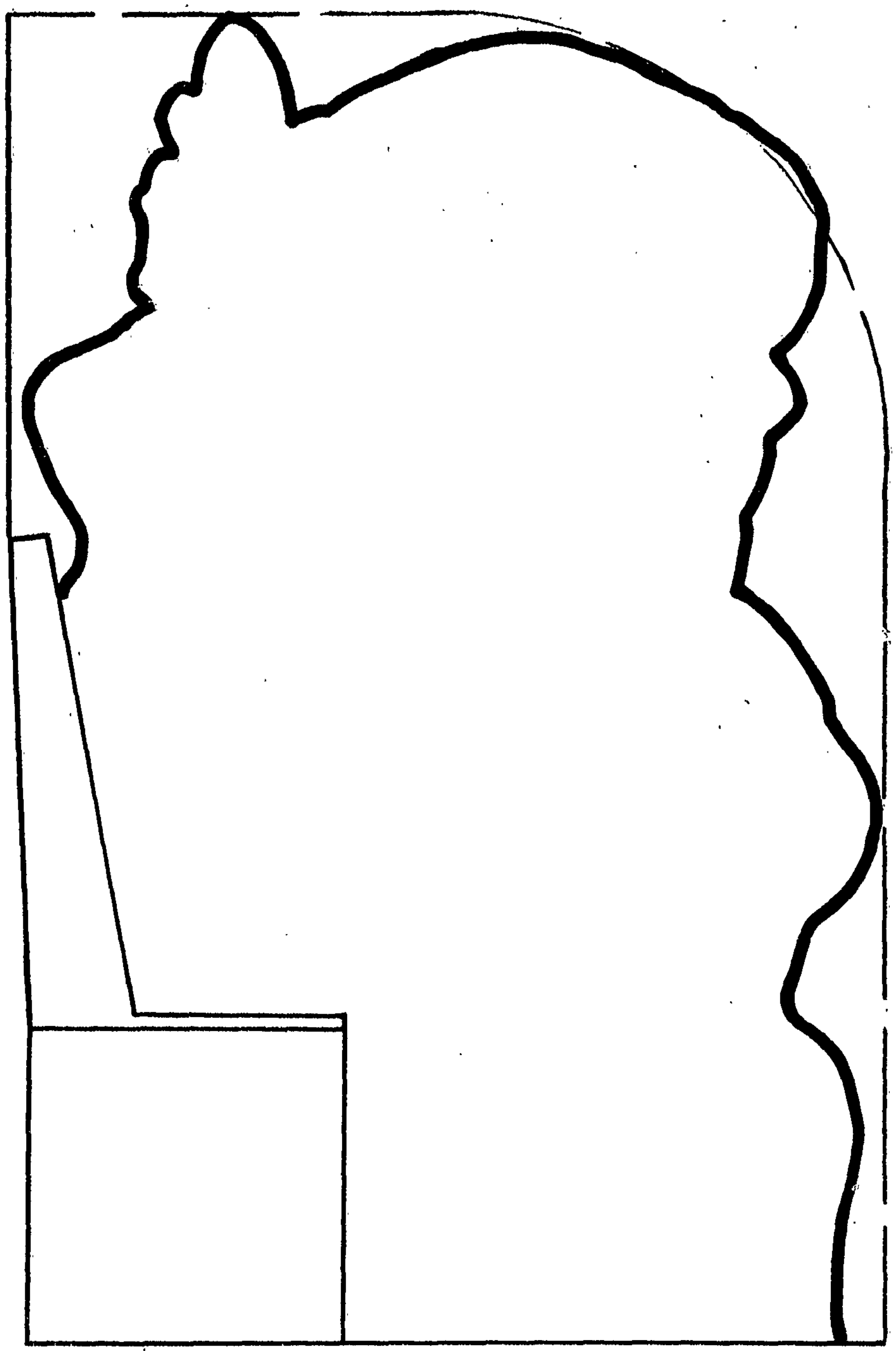

FIGURE 7e
STANDING SIDE
SUBJECT L - 5%ILE
SCALE 8:1

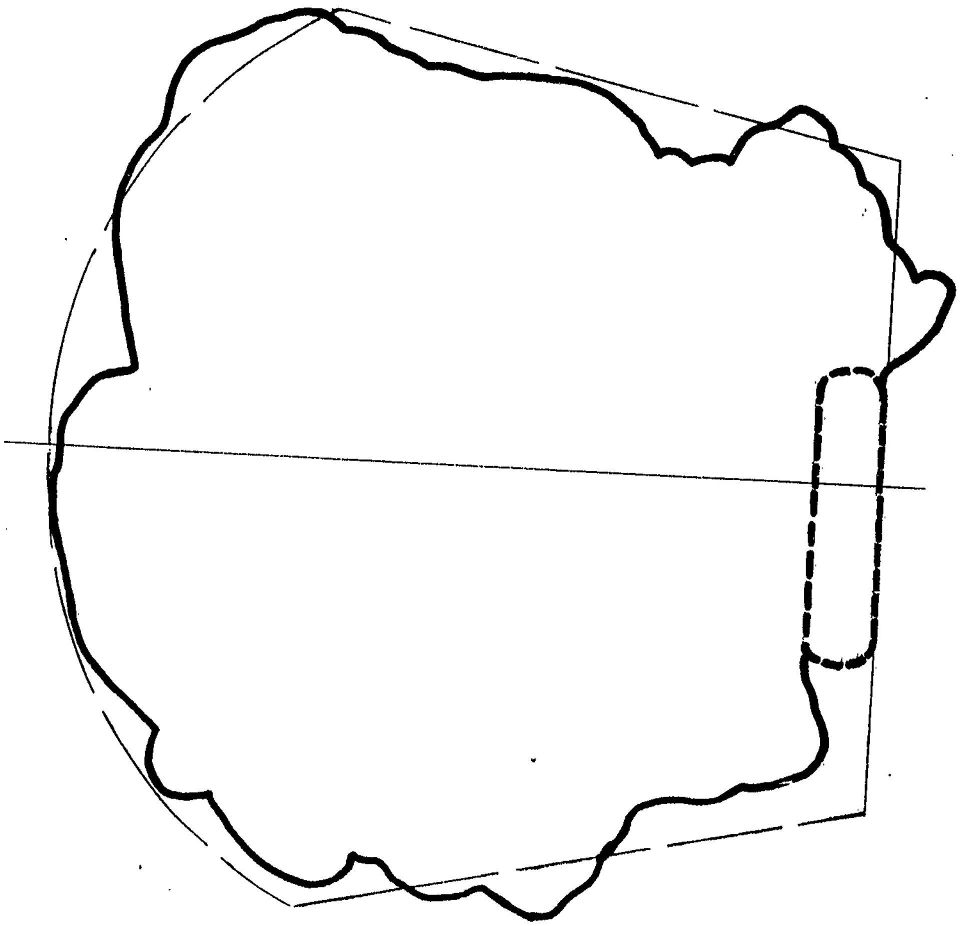

FIGURE 7f
STANDING TOP
SUBJECT L - 5%ILE
SCALE 8:1

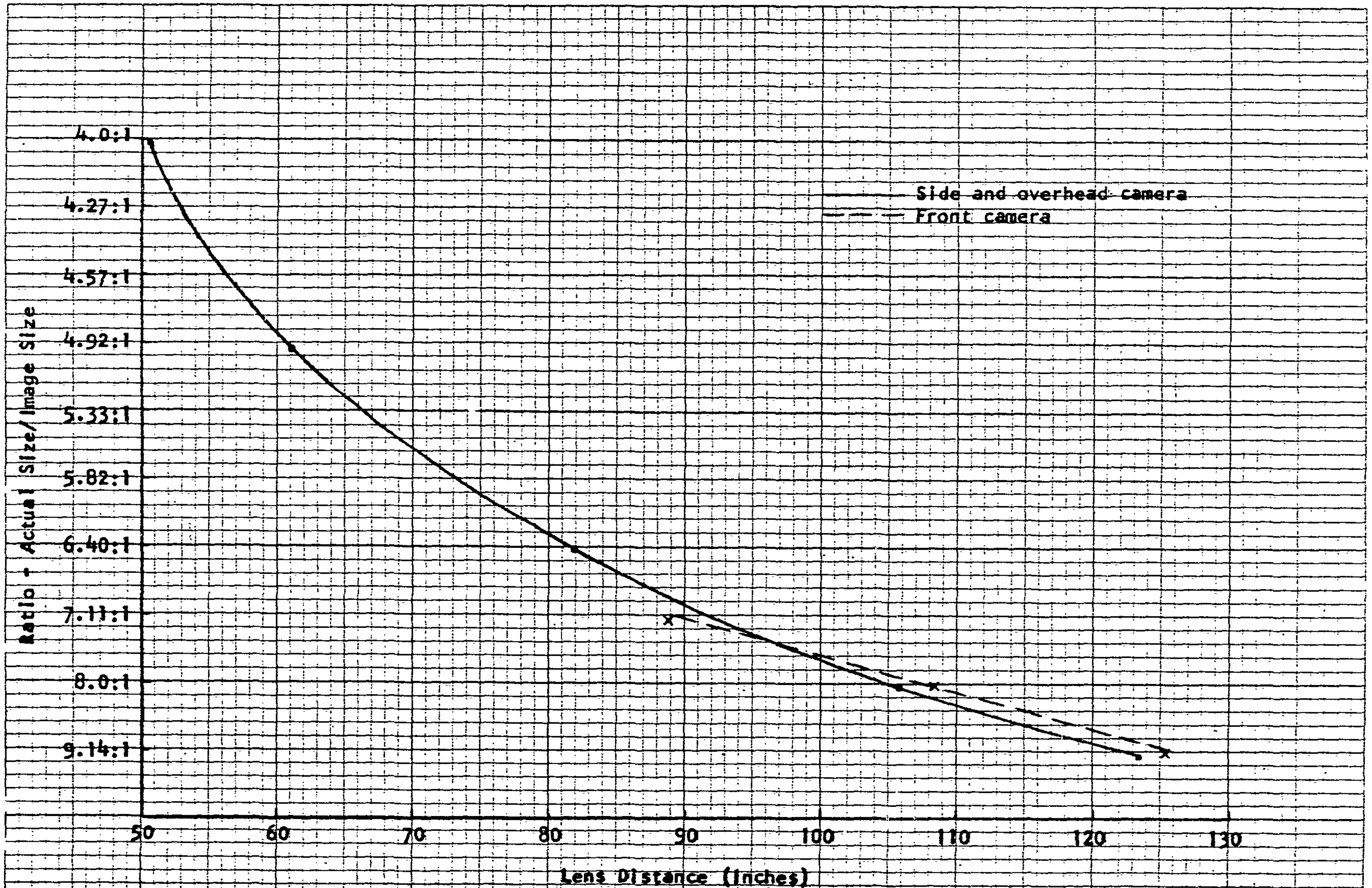

FIGURE 8 - CALIBRATION CURVES FOR THE T.V. CAMERA

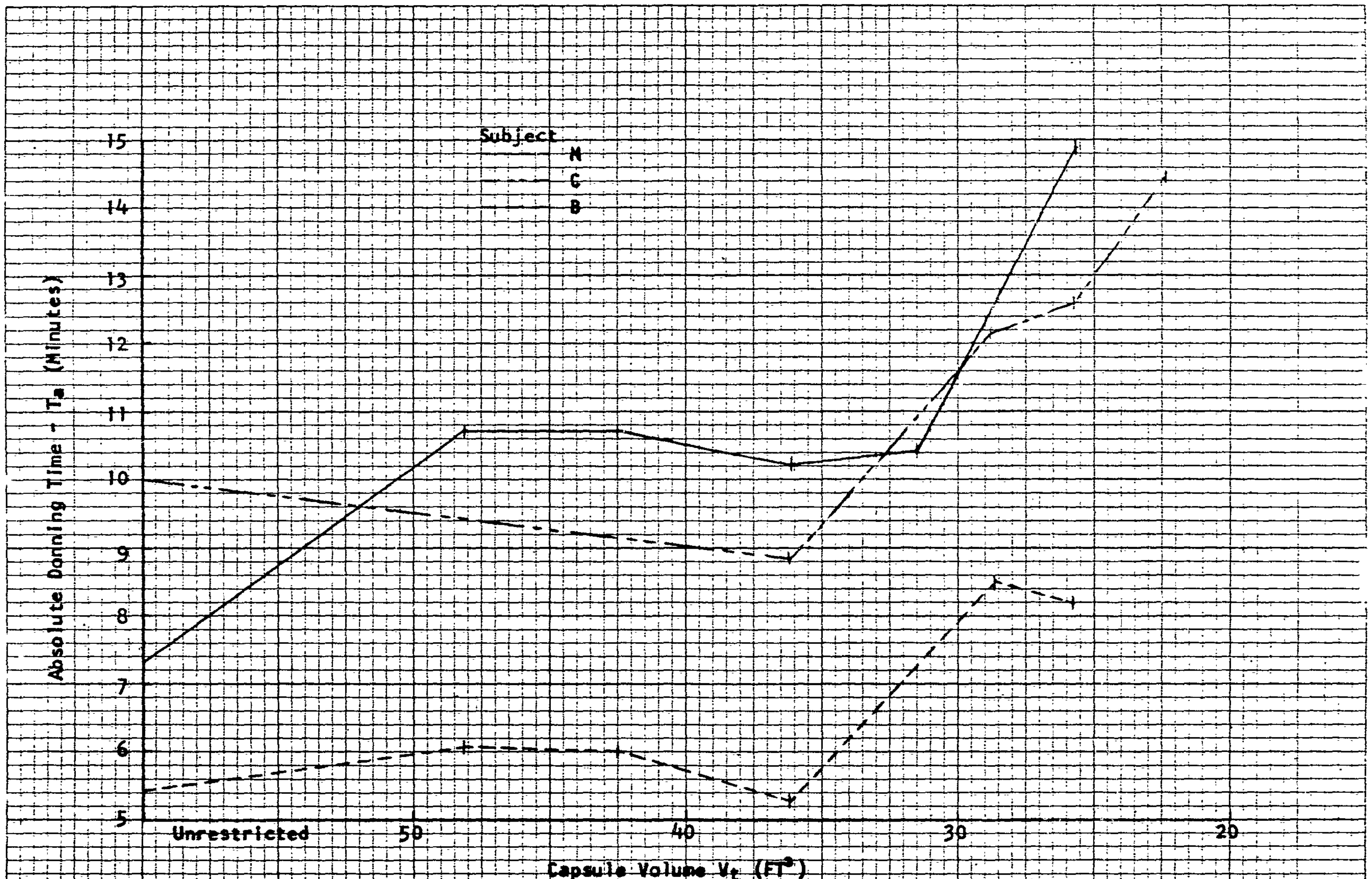

FIGURE 9 - ABSOLUTE DONNING TIME VS VOLUME

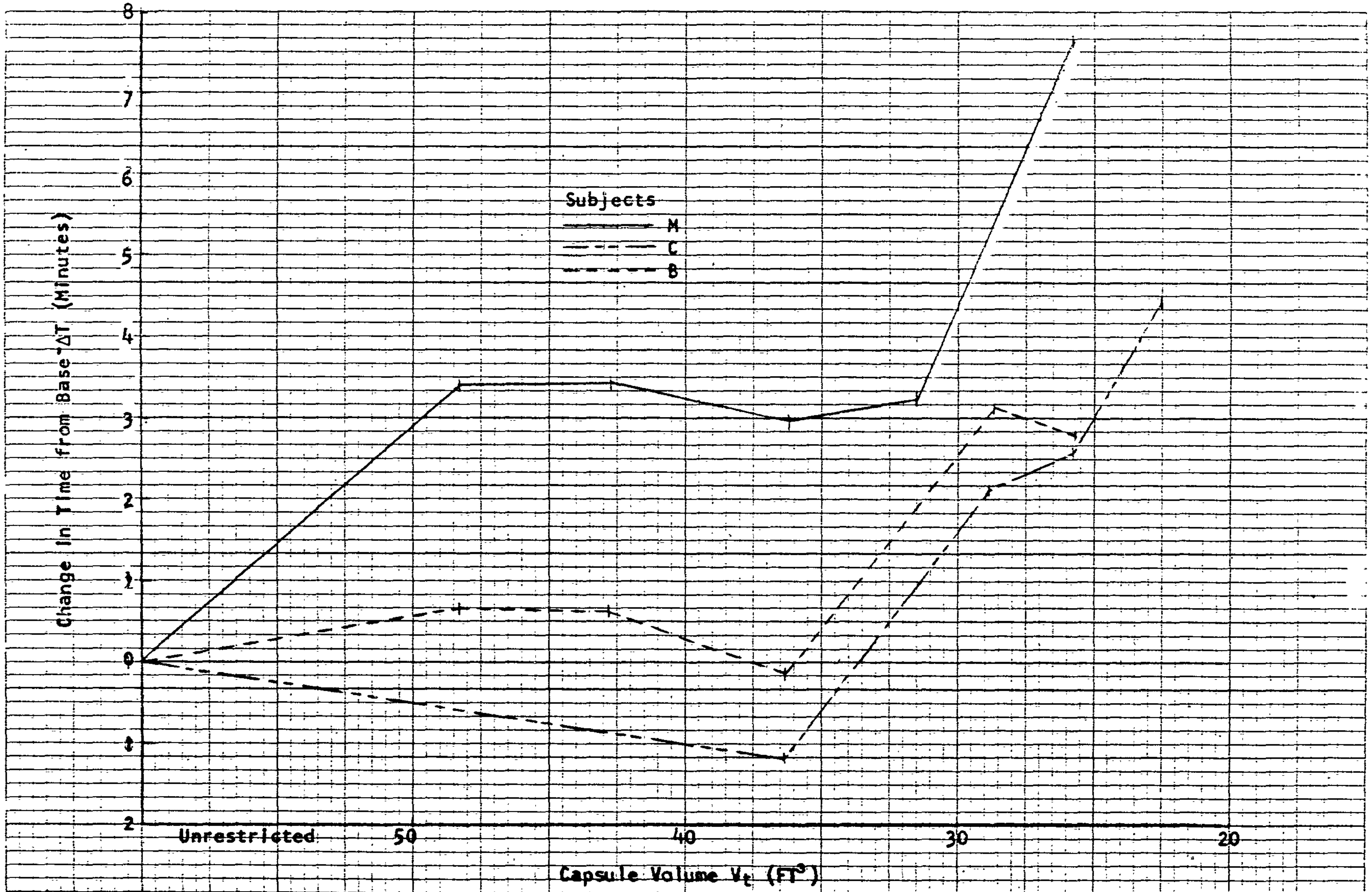

FIGURE 10 - RELATIVE DONNING TIME VS VOLUME

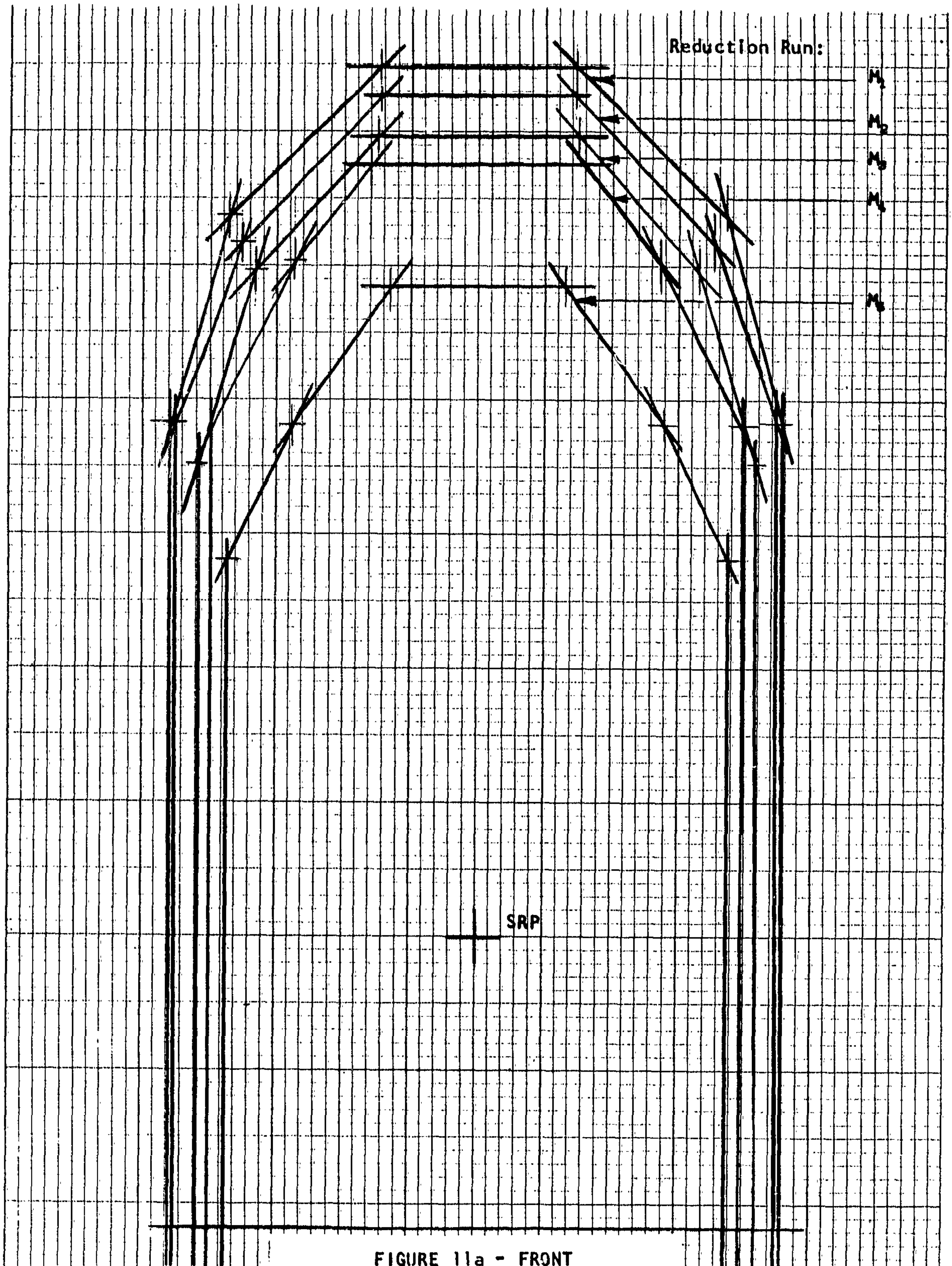

FIGURE 11a - FRONT
SUCCESSIVE REDUCTIONS SUBJECT M
SCALE 8:1

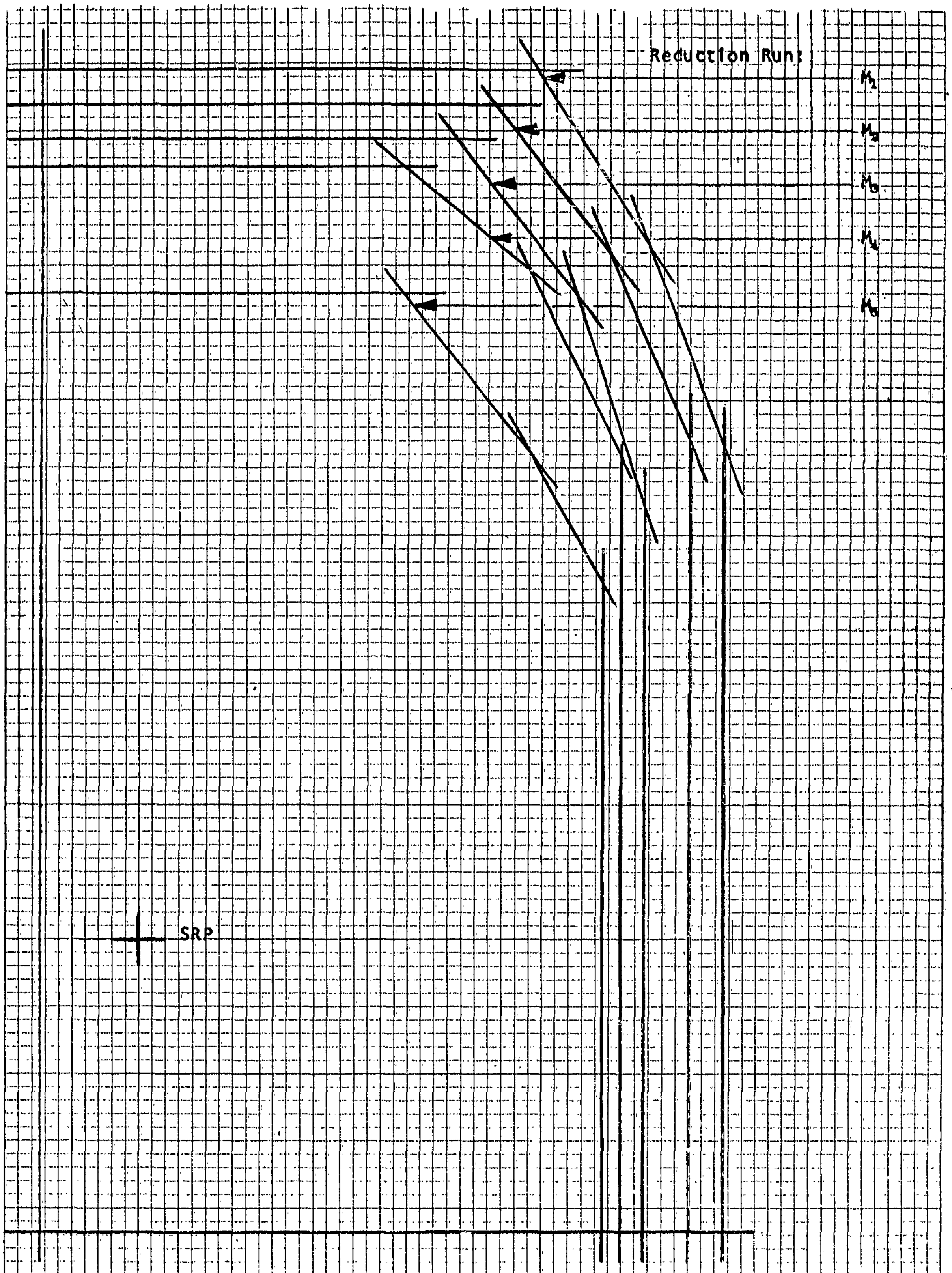

FIGURE 11b - SIDE
SUCCESSIVE REDUCTIONS SUBJECT M
SCALE 8:1

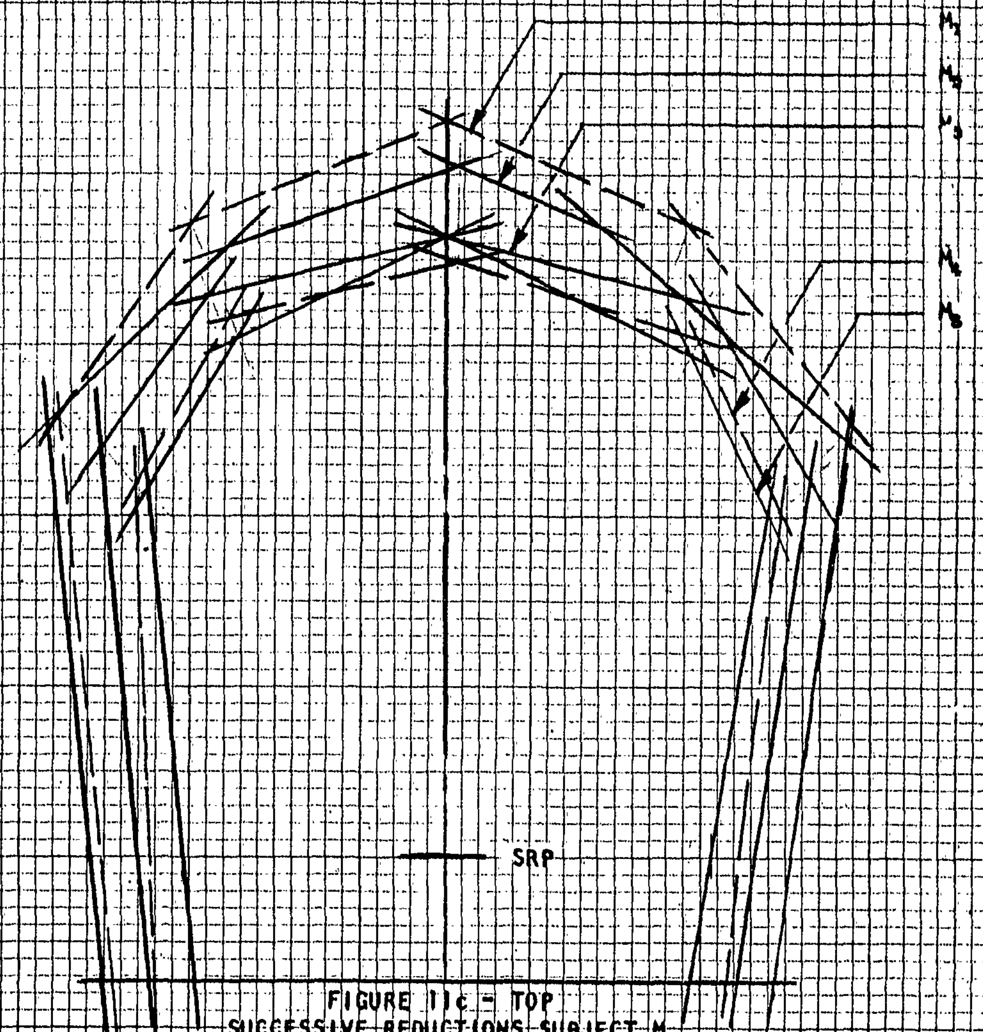

FIGURE 11c - TOP
SUCCESSIVE REDUCTIONS SUBJECT M
SCALE 8:1

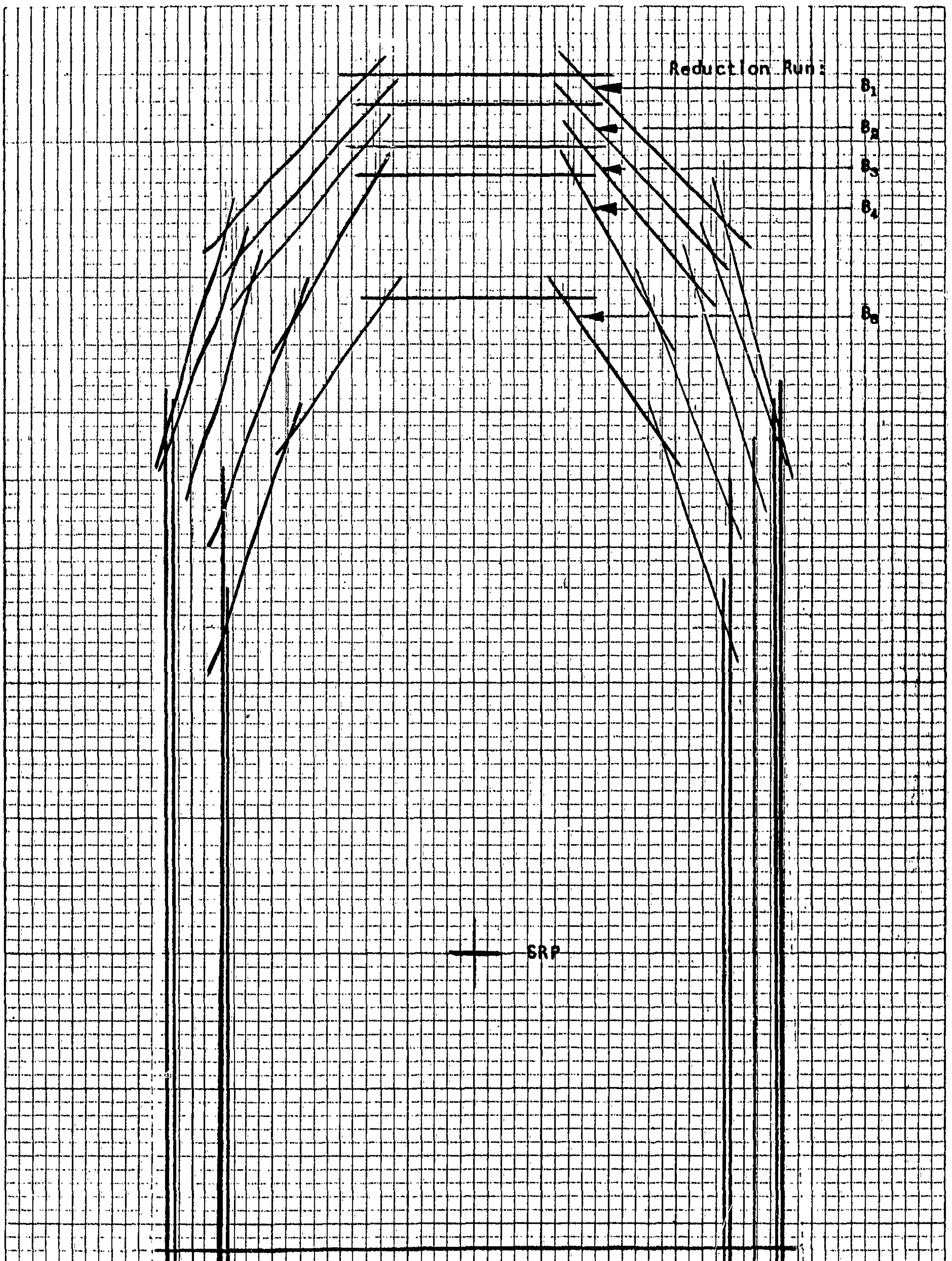

FIGURE 12a - FRONT
SUCCESSIVE REDUCTIONS SUBJECT B
SCALE 8:1

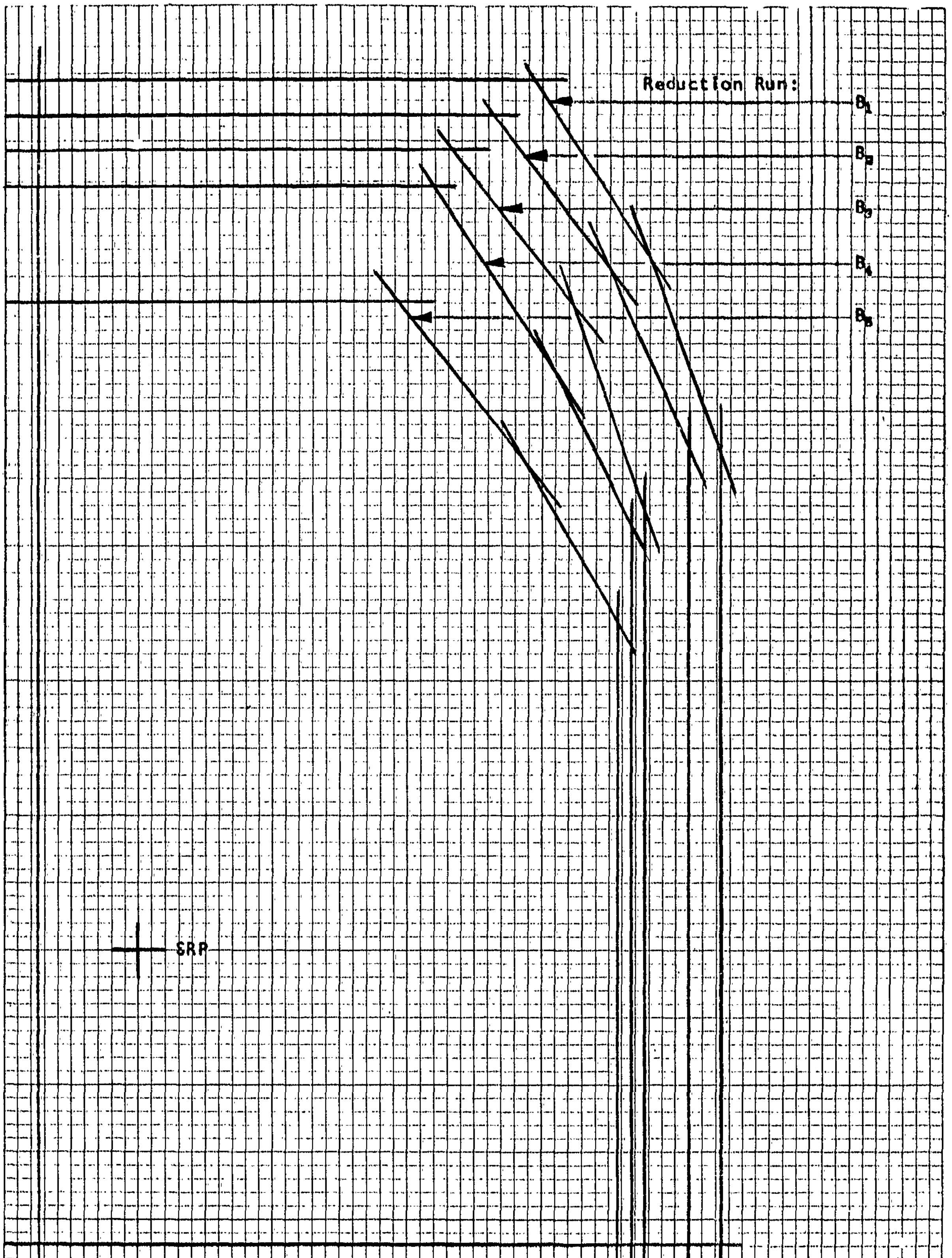

FIGURE 12b - SIDE
SUCCESSIVE REDUCTIONS SUBJECT B
SCALE 8:1

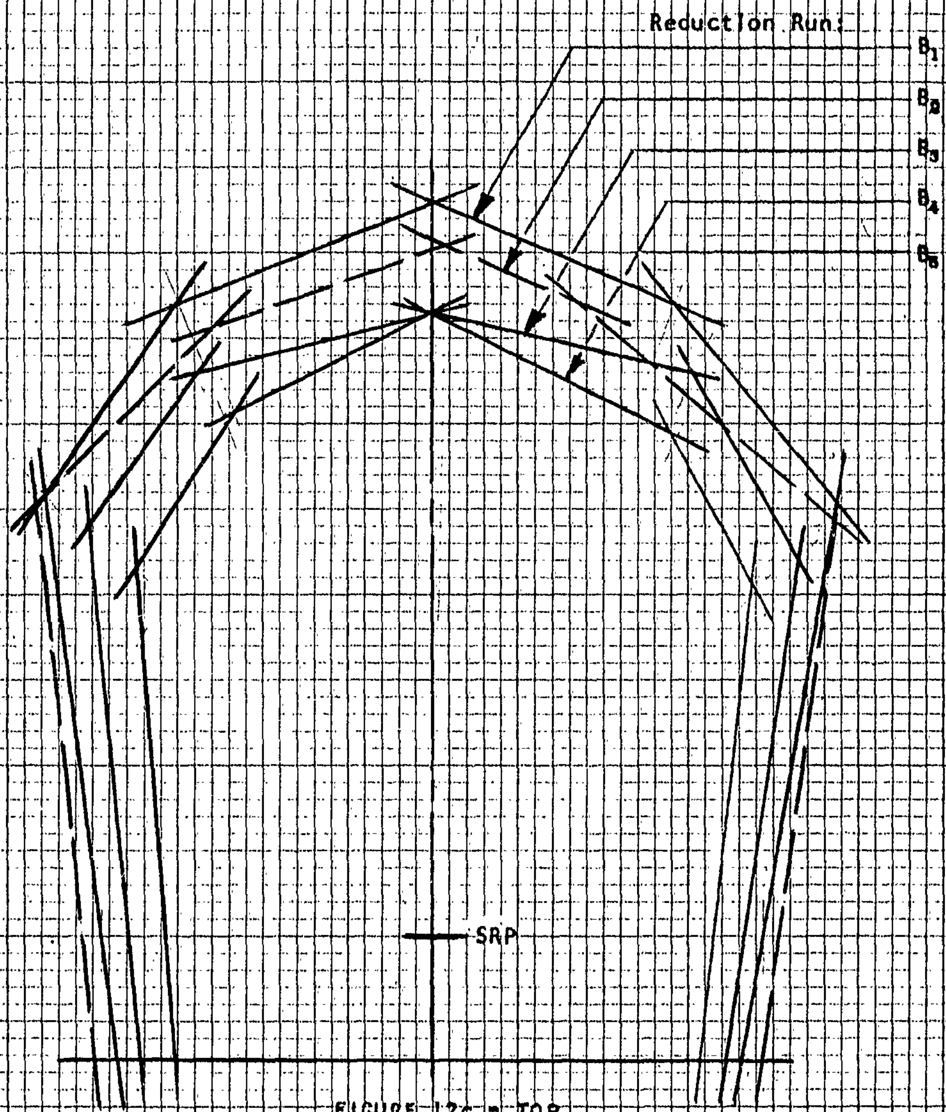

FIGURE 12c - TOP
SUCCESSIVE REDUCTIONS SUBJECT B
SCALE 8:1

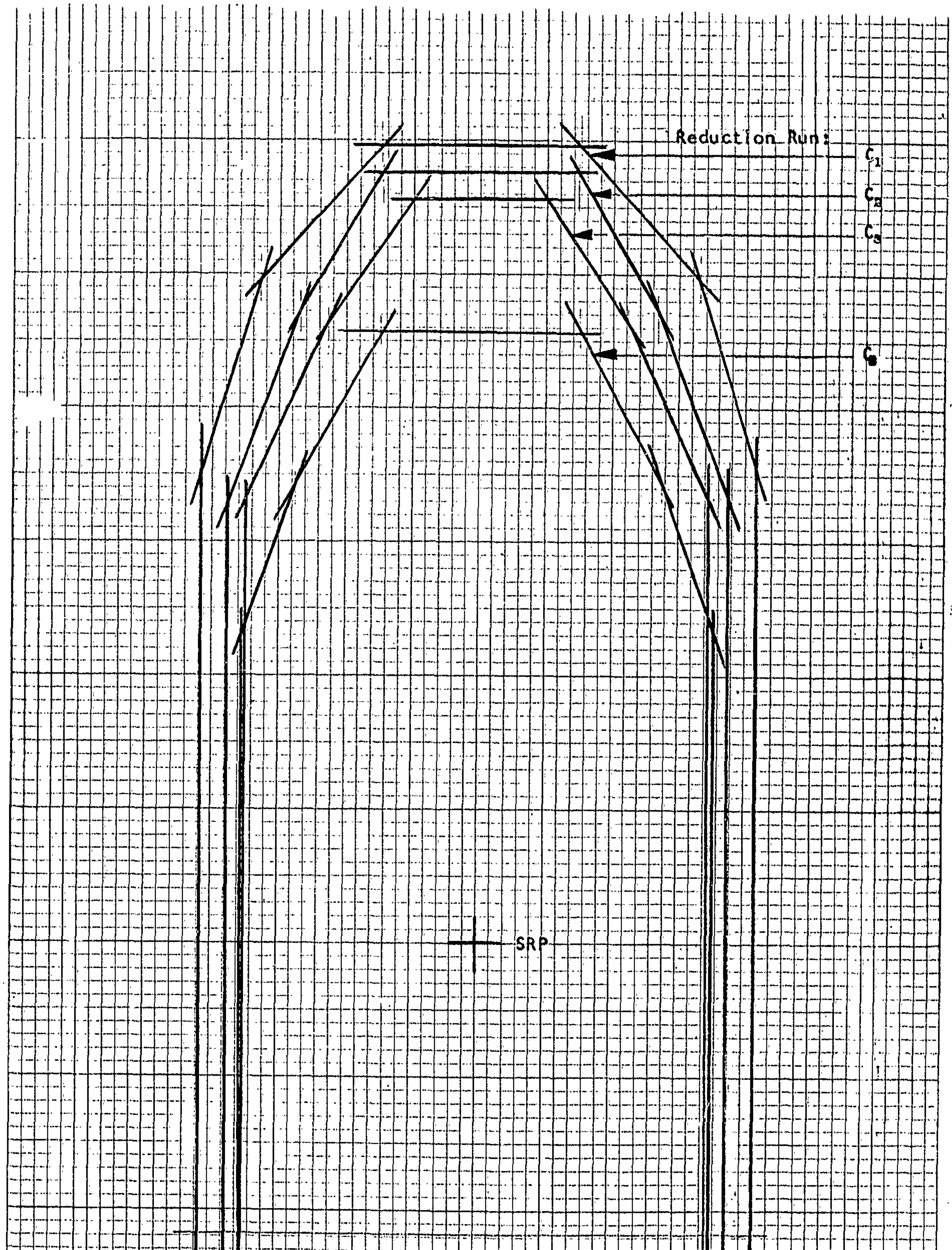

FIGURE 13a - FRONT
SUCCESSIVE REDUCTIONS SUBJECT C
SCALE 8:1

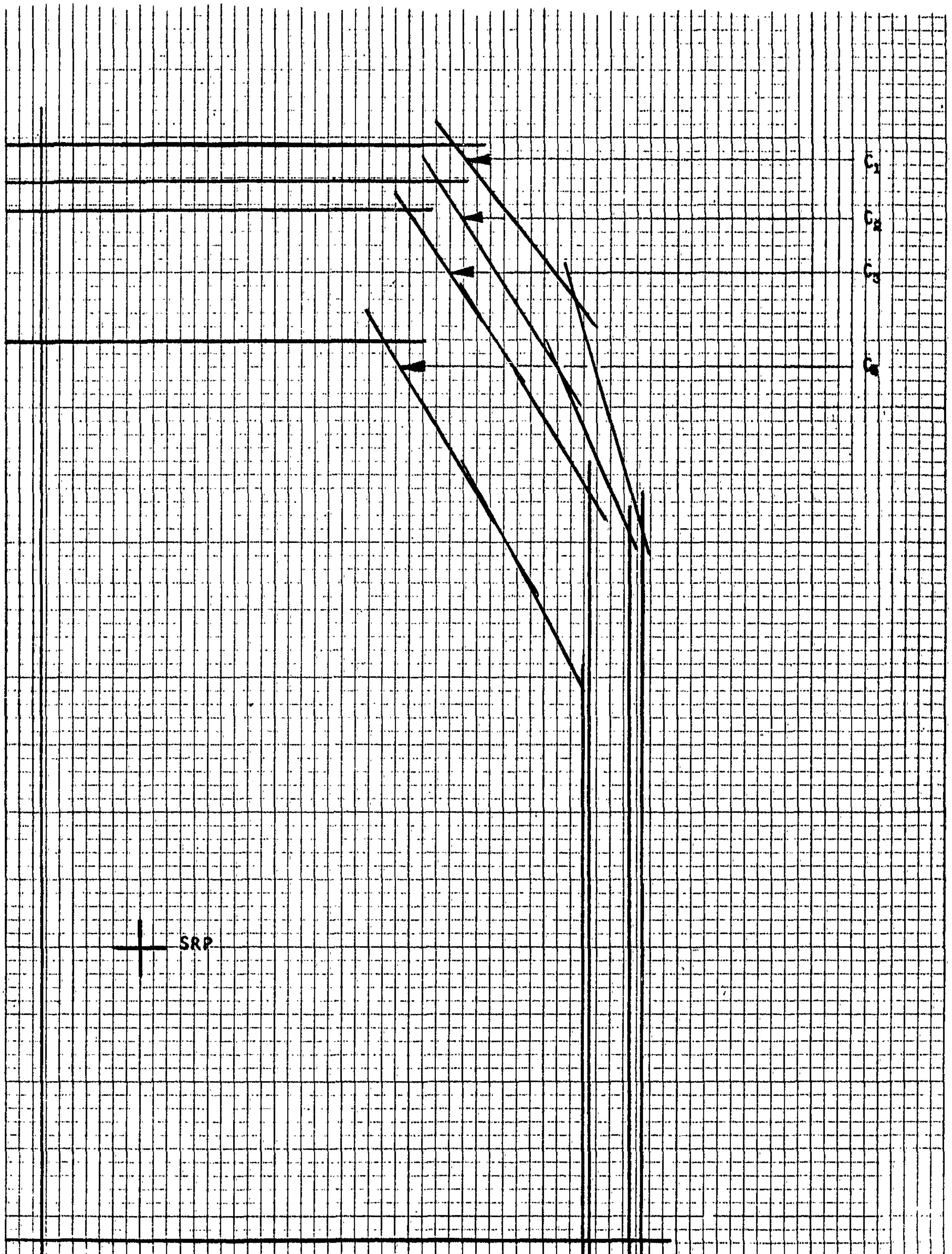

FIGURE 13b - SIDE
SUCCESSIVE REDUCTIONS SUBJECT C
SCALE 8:1

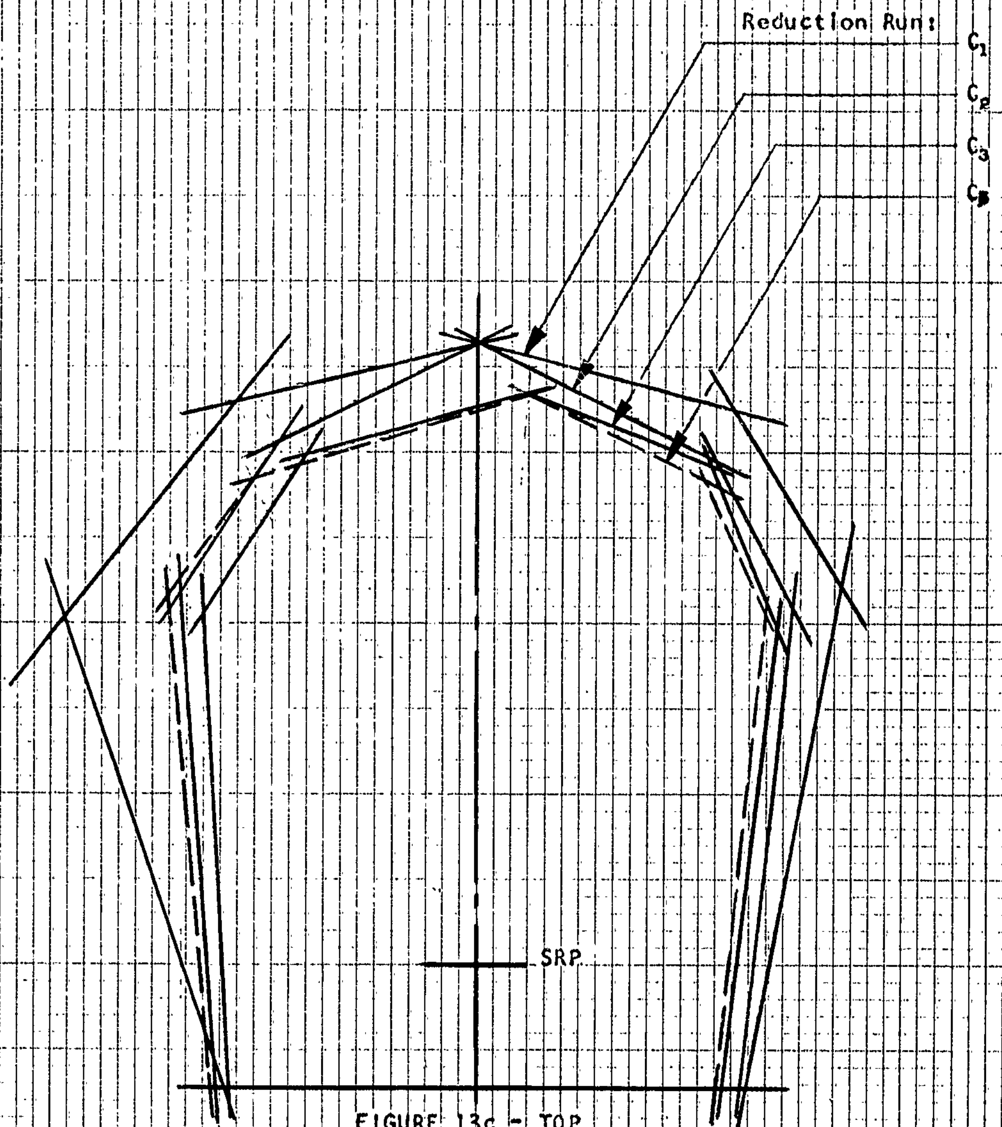

FIGURE 13c - TOP
SUCCESSIVE REDUCTIONS SUBJECT C
SCALE 8:1

U.S. NAVAL AIR ENGINEERING CENTER, PHILA. 12, PA.
AIR CREW EQUIPMENT LABORATORY

1. Report NAEC-ACEL-503
2. Problem Assignment No. 005-AE13-14 (Final report)
3. In DDC collection

SPACE SUIT: DETERMINATION OF THE GEOMETRY AND MINIMUM VOLUME OF THE ENVELOPE REQUIRED FOR DONNING AND DOFFING OF - Geometric and Volumetric Determinations of the Minimal Envelope for Donning the Full Pressure Suit; by B. H. Lowi, LT, MSC, USN and J. R. Provost, 9 p., 3 tables, 39 figures
1 Jul 1963

Upon the request of the National Aeronautics and Space Administration (Manned Spacecraft Center), an investigation was conducted to determine the geometry and internal volume of the minimal envelope for donning the full pressure suit. Specialized techniques were evolved to achieve a systematically variable, transparent, rigid encapsulation of the subject, as well as a parallax-free method for determining the gross three-dimensional excursions of the suit/body silhouette from the nominal configuration. The precise limits of the donning geometry were determined using photoanalysis techniques. Subsequent to the determination of donning geometry, the internal volume was systematically reduced in step-wise decrements along the spherical diameters from the seat reference point, and at each decrement, time to don was recorded. Volumetric and geometric determinations were made on 5th and 95th percentile subjects.

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ABSTRACT CARD OFFSET MARGINAL GUIDE
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